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AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA BASED ON ERTS-1 AND SUPPORTING AIRCRAFT DATA

A report of work done by scientists on 5 campuses of the University of California (Davis, Berkeley, Santa Barbara, Los Angeles and Riverside) under NASA Contract No. NAS 5-21827

color

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Chapter 1

AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA BASED ON ERTS-1 AND SUPPORTING AIRCRAFT DATA (UN047)

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This is the second Type 2 Progress Report dealing with work which has been performed under our integrated study by participants on five campuses of the University of California.

At the time of this writing the first anniversary of the launch of the ERTS-1, the world's first Earth Resources Technology Satellite, is near at hand. The performance of the ERTS-1 four-channel multispectral scanner continues to exceed our fondest expectations and the limitations imposed by cloud cover over our California test sites has not been as severe as had been anticipated. For this combination of reasons we are finding it possible to exploit quite fully both the multiband capability of ERTS-1 and its multidate capability in the integrated studies of earth resources which we currently are conducting in the state of California using remote sensing techniques.

Throughout the present report, emphasis is placed on expressing, in meaningful quantitative terms, the capability of identifying and mapping significant earth resource features by means of an analysis of ERTS-1 data. In several instances, as in Chapter 4, such quantitative data have permitted us to estimate the relative cost-effectives of making earth resources surveys through the use of ERTS-1 either instead of, or in addition to, various other data collection systems. Thus it has become possible, perhaps for the first time, to demonstrate the economies that are possible through the use of a suitable combination of multiband, multidate, and multistage data collection techniques based upon ERTS-1 as the primary data collection system.

In one aspect of this integrated study we are investigating the relative roles which humans and machines should play in the analysis of ERTS-1 data. In this regard, our findings during the present reporting period support the following conclusions, as applied to the present state of the art:

1. <u>A human image analyst can detect broad spatial differences more readily and more accurately than a machine can</u>. Consequently the human excels at drawing broad resource boundaries of the type that are of interest when reconnaissance surveys are being made (e.g., when delineating the boundary separating one "land system" or "stratum" from another). The observation of Winston Churchill that "Nature tends to paint landscapes with a broad brush" is applicable to most of these boundaries. Usually such boundaries are defined on ERTS-1 imagery by virtue of differences in the spatial arrangement of component features on either side of the boundary.

2. On the other hand, <u>a machine is superior to the human for consistently detecting tone or color differences</u>. This observation assumes greatest significance with the land system or stratum defined by any given broad resource boundary. Within such a boundary the several resource components often occupy only a few ERTS-1 resolution cells and tend to be present in a great variety of admixtures. Usually these components are best defined by virtue of their tone or color differences.

Such differences can be readily converted into alphanumeric spectral signatures of the types that are more readily and accurately discerned by machines, through the proper use of automatic data processing techniques, than by humans.

3. In view of the foregoing, <u>a proper combination of human and machine analysis of ERTS-1 data will provide a better earth resource inventory than can be obtained when either type of analysis is used to the exclusion of the other</u>.

As our studies continue we will attempt to document, in highly quantitative terms, the validity of the foregoing conclusions and others which we are in the process of drawing.

Chapter 2

REGIONAL AGRICULTURAL SURVEYS USING ERTS-1 DATA (UN640)

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2.0 INTRODUCTION

In the United States, the Department of Agriculture presently conducts an enumerative program in which virtually all agricultural land is inventoried annually. In addition numerous other federal, state and local agencies conduct extensive crop inventories, land use surveys, and soils mapping projects of varying magnitude. On a worldwide basis it would seem that the principal obstacles to providing enough food for all persons are not merely ones of production but also problems of allocation and distribution. What is needed is knowledge as to where and how much food is now being produced, and how crop production is changing with time. Considering the present needs for regional, national, and worldwide inventory and evaluation data, coupled with the particular capabilities of the ERTS system, agricultural applications appear to be especially promising as an area in which important benefits might be realized from the use of such technology.

Up to the present time agricultural inventories have required a tremendous effort on the part of on-the-ground enumerators, and have presented a formidable data compilation task. However, a satellite sensing system, with which large areas of land can be surveyed in their entirety on one image, and which can provide uniform worldwide coverage with a relatively small number of images, offers great promise as a data collection tool for alleviating these problems. Furthermore, the dynamic nature of agriculture requires not a single evaluation in most cases, but rather a continual updating of conditions. In fact, it has been shown that desired information about agricultural crops can often be obtained only by capitalizing on a knowledge of the patterns of change exhibited by particular crop types under various growing conditions. Again, this suggests that a satellite sensing system such as ERTS, which makes possible regular, frequent observations of each spot on the earth's surface, can provide a service which is both highly desirable and totally infeasible using conventional techniques.

Based on these facts, plus the encouraging results achieved using both high altitude aircraft and spacecraft imagery for crop inventory experiments over the past several years, the Center for Remote Sensing Research (CRSR) at the University of California undertook the experiment described in this report. The experiment was designed to evaluate the feasibility of using satellite data regionally to provide needed agricultural information on an operational basis. The experiment was performed in Maricopa County, Arizona and San Joaquin County, California in cooperation with a number of state and federal agencies (see Table 2.1).

In an effort to accurately determine the degree of detail which can be extracted from ERTS-1 data, and the optimum use of "subsampling" in the form of aerial photography and ground truth data for various agricultural-related tasks, the investigation was carried out in a stepwise fashion beginning with gross land use mapping, and progressing to very detailed surveys. The three major sub-tasks performed were as follows:

1. Delineation of Agricultural Land: An evaluation of the accuracy with which agricultural areas can be differentiated from other land use categories on a periodic (e.g., semi-annual) basis. Such information is necessary for the monitoring of land use change and for the planning of more detailed surveys. In addition this sub-task attempted to assess the feasibility of preparing graphic materials which would illustrate the areal extent of agricultural land, and the changes which have taken place in land use semi-annually.

2. Classification of Agricultural Land: An assessment of the feasibility of performing periodic tabulations of the predominant agricultural use of each square mile of land within each of the general agricultural areas delineated in sub-task 1. This sub-task entailed a breakdown of agricultural areas into general crop type or use groups suggested by the cooperating user agencies as being of particular interest.

3. Crop Inventory: A determination of the accuracy with which the acreage of selected crops (e.g., barley, wheat, and cotton) can be estimated.

In each of the sub-tasks listed above, emphasis was placed on obtaining a quantitative expression of the accuracy of estimates obtained by the use of remote sensing for the county as a whole, and where possible, a comparison of these results with those obtained using conventional techniques. Investigations entailed the use of both human image analysts and automatic classification and data handling techniques, and an evaluation of the optimum mix of human and machine techniques for each analysis problem. In each case, an attempt was made to ensure that the types of information compiled (e.g., maps, tabular data, crop acreages, etc.) conformed to actual requirements or desires as expressed by those persons currently involved in resource evaluations and planning in the test site.

In the area of agricultural land stratification, particular attention was paid to quantitative analyses of the stratifications to ascertain the extent to which they did provide meaningful crop type and condition information (Section 2.1). In so doing, use was made of ground cell information, point sampling along transects (using observers flying in light aircraft), and comparisons with existing land classifications using the FRSL MAPIT techniques. In addition, a study was made of the variation in delineations made at different times during the growing season.

Crop classification and inventory studies progressed concurrently with the stratification investigations, as it seemed likely that any operational inventory procedures would lie heavily dependent on an initial stratification of agriculture on ERTS or other small-scale

TABLE 2.1. USER AGENCY COOPERATION AGRICULTURAL APPLICATIONS PROJECTS

USER GROUP AGENCY	REMOTE SENSING APPLICATION
USDA, STATISTICAL REPORTING SERVICE, CALIFORNIA CROP AND LIVESTOCK REPORTING SERVICE	CLASSIFICATION OF AGRICULTURAL LAND (STRATIFICATION); CROP ACREAGE INVENTORIES
USDA, AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE, BUTTE COUNTY, CALIFORNIA	SUBSIDY AND ALLOTMENT PROGRAM COMPLIANCE MONITORING
CALIFORNIA DEPARTMENT OF WATER RESOURCES, PLANNING STAFF	WATER CONSUMPTIVE USE REQUIREMENT MONITORING IN AGRICULTURAL AREAS
DEPARTMENT OF WATER RESOURCES, CENTRAL DISTRICT	DETECTION OF LAND USE CHANGE AND AGRICULTURAL YIELD REDUCTION DUE TO HYDROLOGIC PROJECTS
UNIVERSITY OF CALIFORNIA, AGRICULTURAL EXTENSION SERVICE	GENERAL AGRICULTURAL EVALUATION AND LAND MANAGEMENT PLANNING

imagery. While some studies were made concurrently on the performance of human image analysts in crop inventories, the bulk of this work was planned to take place at some time after the preparation of this report, due to the dependence of the human interpreter on sequential coverage at certain optimum dates through the growing season. In preparation for the receipt of ERTS data covering the test site on the required dates, plans were developed for an efficient point sampling procedure for extracting crop acreage statistics from ERTS data on a regional basis (Section 2.3.1).

Very significant progress was made during the past year on the development of automatic data processing techniques for the detailed classification of agricultural lands (Section 2.3.2). In particular, emphasis was placed on the optimum interface between human interpreters and the computer. Thus, initial stratification of agricultural land were performed manually, and the resultant information used in the classification process. In addition, a sampling procedure was designed which would optimize processing of remote sensing and ground data by reducing the amount of ground information required (Section 2.4). Incorporated in the design is provision for the weighting of classification errors based on the relative importance of errors regarding various crops. Finally, studies were conducted to estimate the relative costs of performing crop inventories using various combinations of human and computer data processing inputs.

2.1 AGRICULTURAL LAND USE STRATIFICATION AND CLASSIFICATION

At the present time statistical information gathering organizations such as the Statistical Reporting Service, U.S. Department of Agriculture, (SRS) often use a statewide land "stratification" as a first step in the allocation of ground enumeration samples. The general purpose of stratification is to improve sampling efficiency by decreasing the variance within a set of samples so that more precise estimates can be made from those samples. Within each stratum, sample plots are chosen and classified by ground personnel as to crop type and acreage, intended use of that crop, intentions of double cropping, etc. Also additional sampling data are gathered through the use of questionnaires sent to voluntary subscribing farm operators. All of the resulting information is weighted and "expanded" to provide state estimates as well as a national estimate. The major restriction upon such a stratification design is that both the boundaries and the areas of the strata must be accurately determined. If this condition is not met, serious bias may result in the population estimates.

Stratifications are now produced by the SRS with the use of conventional aerial photography and are often up to 8 years out of date. That portion of the Statistical Reporting Service's stratification for California within San Joaquin County shows five different land use strata

within the county, i.e., urban areas, non-agricultural areas, irrigated agricultural areas, dry land agricultural areas, and rangeland areas. This stratification is presently badly outdated. For example, in one area a large tract of land classified as dryland agricultural is now occupied by a man-made reservoir, and in other areas that are similarly classified, irrigated agriculture has replaced dry-land farming. Thus, such stratifications can quickly become inaccurate. ERTS-1 imagery with its synoptic characteristics and possibility of providing more frequent coverage, however, appears to offer a solution to the problem posed by out-of-date strata boundaries.

In an attempt to evaluate the use of satellite imagery for this purpose, all land within San Joaquin County was delineated by image analysts into broad land use and crop category classes based on their appearance on the ERTS-1 July 26th (summer season) color composite image.* The stratification of the agricultural land use categories proved to be a relatively simple task, taking each of three interpreters approximately 30 minutes to complete. The three interpretations were quite similar, requiring only minor revisions to produce a "consensus" stratification. A total of thirteen different agricultural strata were recognized, differing both in general field size and relative proportions of crop types and field conditions. Upon comparing these interpretations we concluded that nearly all boundaries were truly representative of differing cropping practices. In a number of cases, the stratifications agreed almost exactly with major soil type boundaries as drawn by earlier soils surveys.

Figure 2.2 illustrates the strata boundaries as drawn on the ERTS-1 photograph, while Table 2.2 presents a description of each of the strata categories in terms of land use and cropping practices. In Figure 2.1 the strata as drawn on the ERTS-1 photo can be compared with a land use and crop map of San Joaquin County which was compiled at the time of the 1952 soil survey for the county. Differences in the two maps may be due in part to (1) changes that have taken place since 1952, (2) inaccuracies in the 1952 map, and (3) the inability of the interpreters to detect all meaningful land use patterns on the ERTS-1 image.

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*Due to the lag time between the date of ERTS photography and our receipt of NASA-produced color composite images of the test areas (three to six months) it was necessary to devise two in-house techniques for producing color images suitable for interpretation: (1) the "diazo technique", wherein each of several spectral bands or dates of imagery is printed on a separate sheet of diazochrome color transparency material, and these "sandwiched" together in register to form the color composite, and (2) the "direct color film technique", in which the several black-and-white images to be composited are each exposed on the same piece of color film in register (i.e., a multiple exposure of the color film is made), while in each case a different color filter is interposed between the black-and-white image and the copy camera lens. Throughout this chapter, the term, "ERTS color composite" generally refers to an image produced by one of these two methods.

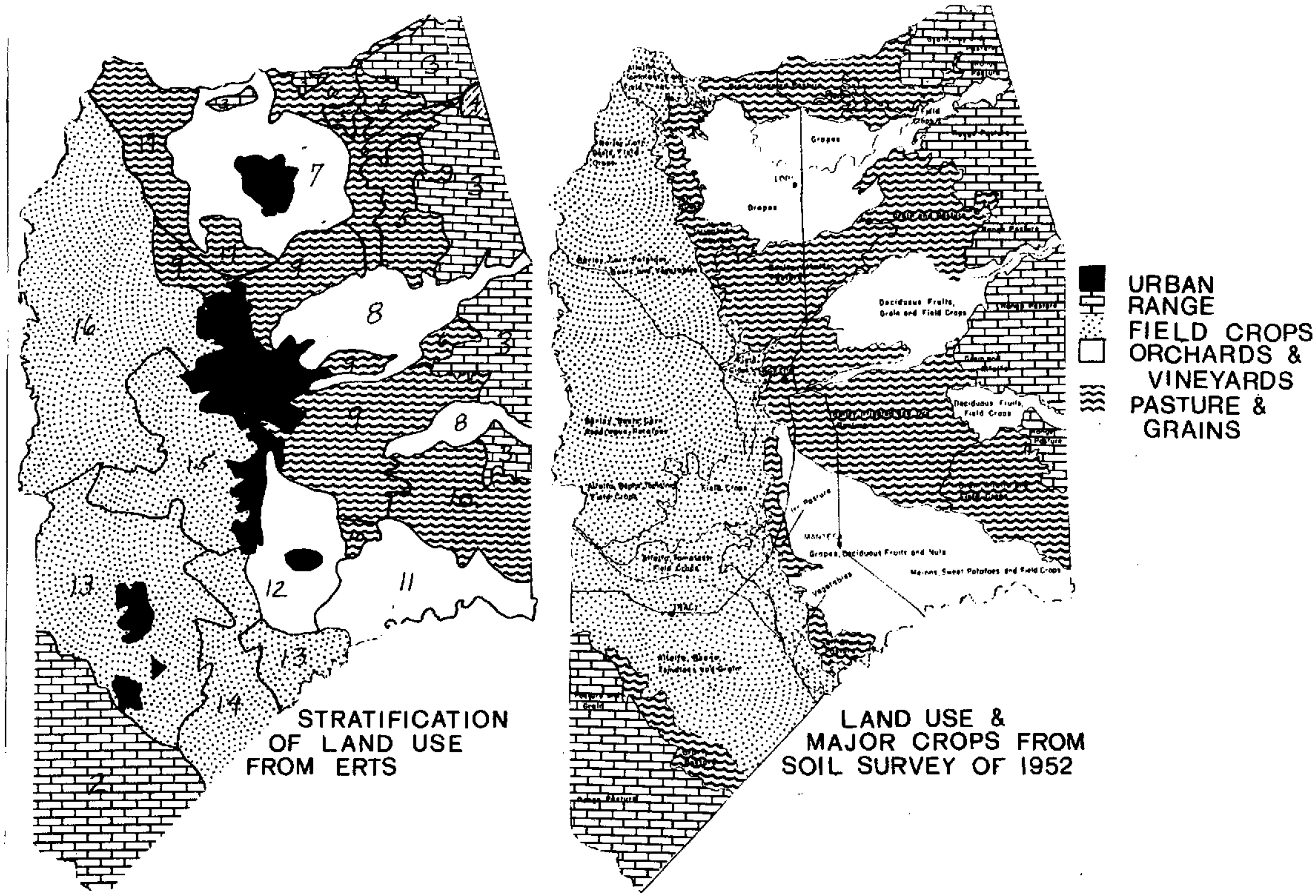

Figure 2.1. Comparison of agricultural stratification of the San Joaquin County test site as interpreted on a color composite (made from ERTS-1 data acquired on July 26, 1973) with the generalized land use and major crop map from the 1953 Soils Survey of San Joaquin County.*

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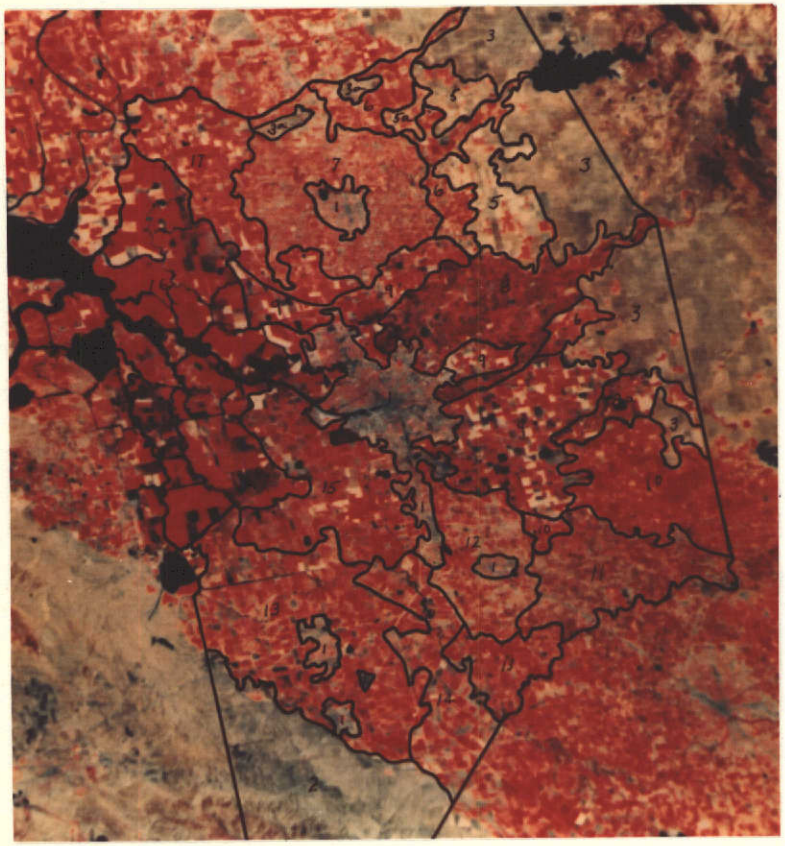
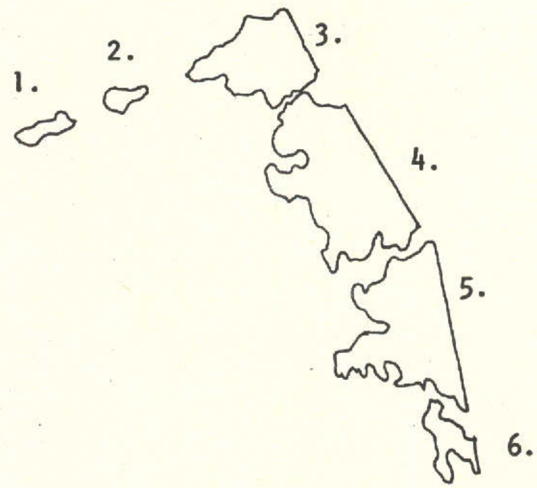
*Weir, Walter W. 1952. Soils of San Joaquin County, California. University of California, College of Agriculture, Agricultural Experiment Station. Berkeley, California. June.





STRATA 3 -- IMPROVED GRASSLAND

1.	AREA*	+0000018025
2.	AREA*	+0000016586
3.	AREA*	+0000156313
4.	AREA*	+0000311408
5.	AREA*	+0000253004
6.	AREA*	+0000041626

Figure 2.2. The computer print-out on the right represents the digitized boundaries and relative areas (expressed here in terms of 4×10^{-6} square inches on the digitized photo) of the "improved grassland" stratum as delineated by an interpreter on the ERTS-1 color composite image on the left. The ERTS image, on which the entire San Joaquin County test site is outlined, was taken on July 26, 1972. As reproduced here, one inch on the image represents approximately 12 miles on the ground.

TABLE 2.2. DESCRIPTION OF LAND USE STRATA IN SAN JOAQUIN COUNTY, CALIFORNIA, DELINEATED USING ERTS-1 JULY, 1972 IMAGERY

Stratum #	Image Characteristics*	Predominant Land Use
1	Irregularly shaped areas of deep or light blue, with irregularly shaped areas of light pink or medium red. Often in larger areas, light blue linears can be seen. Usually extremely fine textured.	Urban and city areas, and non-agricultural cultural features such as military depots, airports, and sewage treatment facilities.
2	Irregular areas of light to dark grayish blue. Irregular texture with no regular geometric pattern.	Rangeland located in steep topography.
3	Dark gray to light gray-green elements that occur in a coarse rectilinear pattern of dark and light tones.	Fenced rangeland on rolling topography, some improved grassland.
4	Very dark blue-black in color with a smooth and uniform texture.	Water-bodies, both natural and man-made.
5	Medium red, white, and grayish-green elements arranged in a coarse textured rectilinear pattern.	Dryland grain crops, irrigated pasture, and improved rangeland on rolling topography.
6	Mostly medium to dark red elements with some lesser amounts of white and grayish elements within an overall pattern of adjacent rectangular elements.	Irrigated pasture, fruit orchards and vineyards.
7	Irregularly alternating pattern of small light red and gray or white rectangular units.	Vineyards with minor amounts of fruit and nut orchards, field crops, and irrigated pasture.
8	Irregularly alternating pattern of medium-sized dark red and medium red rectangular field elements with minor amounts of black or white rectangular fields.	Fruit and nut orchards with minor amounts of field crops.
9	Irregularly alternating pattern of large black, white and medium red rectangular units.	Small grain crops (some non-irrigated) with an equal proportion of field crops (sugar beets, alfalfa), and some irrigated pasture.
10	Irregularly grouped pattern of medium sized deep red or medium red rectangular field units.	Irrigated pasture and rice fields with some fruit and nut orchards and vineyards.
11	Irregular groups of small dark red, medium red and light blue fields.	Nut orchards with some fruit orchards and vineyards.
12	Irregular groups of small-sized medium red and light blue rectangular fields.	Vineyards with some fruit and nut orchards.
13	Irregularly alternating pattern of large red, pink, light orange, black, and gray rectangular and triangular fields.	Field crops such as safflower, beans, small grains, and alfalfa.
14	Large rectangular field units with equal proportions of medium red, light red, bluish gray and black fields.	Field crops such as beans, alfalfa, sugar beets, and small grains.
15	Medium to large rectangular field units medium to dark red, white or black in color.	Field crops such as sugar beets, corn, and alfalfa.
16	Large irregular or rectangular field units predominantly deep red in color with some black or white colored fields.	Field crops such as asparagas, corn, alfalfa, and sugar beets.
17	Medium to large rectangular field units, mostly medium red to deep red with some white or black fields.	Irrigated pasture and field crops with minor vineyard areas.

*as seen on simulated infrared ektachrome color composite imagery made from July 26, 1972 coverage obtained with MSS bands 4, 5 and 7.

Certainly a much more detailed and up-to-date stratification was produced from the ERTS image than is currently used by the SRS. The obvious questions arise, however, as to whether: (1) the strata as drawn on the image are meaningful in terms of actual land use conditions, (2) the strata delineations would change throughout the year, and (3) such a detailed delineation could enable the SRS to more efficiently and accurately estimate the parameters of interest on a statewide basis. The following sections of this report deal with answers to the first two questions. It is hoped that future cooperative studies with the SRS will provide an answer to the third.

In addition to their possible use by agencies such as the SRS, the stratifications performed by the human interpreters are proving to be of great interest as the preliminary step prior to detailed classification of crop types on a field by field basis. As will be explained in detail later in this chapter, by far the most practical and cost-effective method for producing "automated crop inventories" involves the use of manual interpretation at several stages in the process. In particular, it has been found that automatic classification done stratum by stratum, using training data specific to each stratum results in much greater classification accuracy than would be possible otherwise. Furthermore, it is much more efficient to allow a human to do the preliminary stratification than to attempt this wholly with automated techniques. Thus an interactive man-machine system, in which each is used to perform only those tasks for which it is best suited, results in the greatest overall efficiency in terms of time and money expended for a given level of classification accuracy.

The final section of this chapter (Section 2.5) consists of a comprehensive discussion of both the hardware and software components of the automatic image classification and data processing system developed at the Center for Remote Sensing Research.

2.1.1 Stratification Analysis with MAPIT

The stratification boundaries as drawn by human interpreters on the July 26, 1972 ERTS-1 imagery have been digitized, and these data profiles stored for future retrieval. The resulting data bank can be used in the future to accomplish the following:

1. Provide area information for individual strata from an analysis of the digitized boundary coordinates. The relative areas of strata must be accurately determined in order to avoid possible bias in subsequent sampling designs.

2. Monitor the degree to which strata boundaries change as delineated on imagery acquired at different times throughout the year. This is done by comparing data profiles on a sequential basis. In

those cases where differences occur, it can be determined whether the boundary shift is due to temporal changes in the vegetation appearance or to actual shifts in land use (as derived from ground data cell information).

3. Once the delineations have been digitized, they can be compared with data from other sources. For example, the Statistical Reporting Service, USDA, stratifies all agricultural areas throughout the nation using conventional panchromatic aerial photography. Once digitized, the SRS strata boundaries of San Joaquin County could be compared with those derived from ERTS-1 imagery.

4. The digitized information greatly increases the efficiency with which a point by point classification can be made using the automated CALSCAN process. Figure 2.2 shows Stratum 3 (improved grassland) in San Joaquin County, California, and the relative areas of its various sub-strata as they were digitized from delineations drawn on the July 26 ERTS-1 color composite image of the test site. These digitized data can be reproduced to any desired scale (e.g., 1:250,000 which would be compatible to USGS map sheets). The relative areas of the various sub-strata expressed in units of 4×10^{-6} square inches on the print-out map, are easily converted to acreage figures using known scaling factors.

2.1.2 Quantitative Evaluation of Stratification

A study was conducted to determine how to best quantify the correlation between the land use/crop type strata as delineated on ERTS-1 imagery and actual ground conditions. Such an evaluation is required before these strata can be efficiently used as an integral part of an operational crop inventory. The delineation of strata constitutes a preliminary step in a multistage sampling design for determining crop yield, and/or as a method of determining the annual and permanent shifts in land use.

Two years before the launch of ERTS-1, the CRSR established 48 four-square-mile permanent ground data cells in San Joaquin County to monitor the annual cycle of crop development. It became evident soon after the receipt of the first ERTS-1 imagery that these cells would be of limited use for quantitative evaluation of the strata. Because the cells were established without the aid of small scale imagery, several of the strata contained no cells, and furthermore, the forty-eight cells did not provide an adequate number of data points for a proper evaluation.

It was determined that an optimum method for collecting the ground data necessary for meaningful evaluation of the land use/crop type strata would need to provide for the following: (1) rapid collection of the data because of the large areal extent of the county and the possibility of having to repeat such a data collection effort periodically to account for double cropping, (2) collection of a large

number of data points to ensure that each stratum would be sampled, and (3) rapid evaluation of the collected data. The first two constraints suggested that the data should be collected from low flying aircraft, while the third could be met provided that the data were collected from "point sample" sites.

On January 4, 1973 (to coincide with an ERTS overflight) six east-west sample lines across the county were flown (Figure 2.3). These lines were chosen so as to cross most of the strata that were delineated on the July 26, 1972, ERTS-1 color composite. While flying at 95 miles per hour at an altitude of 500 feet, an observer tallied the land use/crop type category that appeared at a prescribed angle below the aircraft. This was done at ten second intervals. On the average, 130 observations were made per line. At frequent intervals between observations the aircraft's position along the flight line was recorded either by noting predominant geographic features below, or by taking photographs. It should be noted that the photos were used later only for point location, and that all land use/crop type identification was done by real time observation.

In the office, each flight observation was plotted on a map and assigned to one of the strata. Ten land use/crop type categories were employed: (1) cereal and grain crops, (2) forage crops, (3) sugar beets, (4) asparagus, (5) grapes, (6) deciduous fruit and nut crops, (7) pasture, (8) rangeland, (9) fallow cropland, and (10) urban, non-agriculture. These types were chosen because of their frequency of occurrence and economic importance. If such data had been collected later in the spring, many more crop types could have been recognized. For example, the deciduous fruit and nut crops probably could have been subdivided into fruit crops or nut crops, and the cereal and grain crops into specific crops such as wheat, barley and corn. However, it must be remembered that if more crop classes had been chosen, a larger sample would have been needed to adequately evaluate the strata.

In order to test the hypothesis of independence between the two variables of classification, i.e., stratum and land use/crop type category by the χ^2 criterion, the data were organized into a contingency table (Table 2.3). The hypothesis of independence implies that the proportion of land in each land use/crop type category is constant from stratum to stratum. If there is no independence, and hence a large calculated χ^2 value, there is said to be interaction, implying that the proportion of any given land use/crop type category varies from stratum to stratum, which would indicate that the delineations as drawn by the interpreters were indeed meaningful. (A complete description of this analysis procedure can be found in Chapter 19, "Principles and Procedures of Statistics", by Robert G. D. Steel and James H. Torrie, McGraw-Hill Book Company, Inc., 1960).

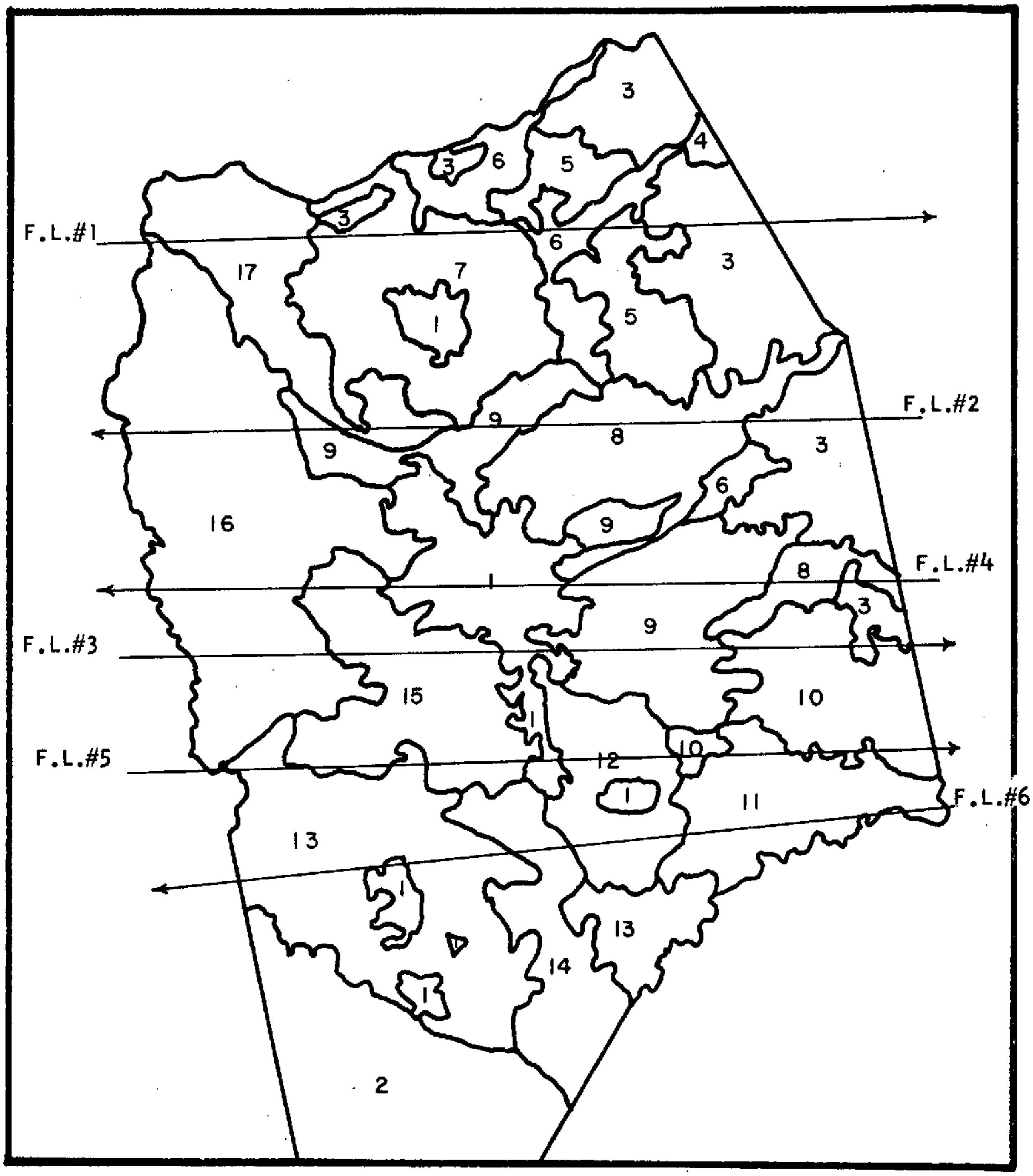


Figure 2.3. This map illustrates the land use/crop type strata delineations for San Joaquin County as drawn by photo interpreters using the July, 1972 ERTS color composite image. It also shows the lines flown at low altitude to gather "ground truth" for purposes of evaluating the significance of these strata and the strata delineated on a January 1973 ERTS color composite.

TABLE 2.3. CONTINGENCY TABLE OF X^2 VALUES AND FREQUENCY, BY STRATA, OF THE VARIOUS LAND USE/CROP TYPE CATEGORIES AS DELINEATED ON JULY ERTS-1 IMAGERY*

Category		Stratum												Total
		1	3	7	8	8a	9	11	12	13	14	15	16	
Cereal and Grain Crops	Observed	3	0	0	1	1	6	0	0	0	0	3	9	23
	Chi-square	1.9060	1.0166	1.6974	.0006	.0184	1.9992	2.2471	1.2304	2.6726	.9315	.1639	8.0664	21.9501
Forage Crops	Observed	2	1	1	0	5	10	2	3	10	1	13	7	55
	Chi-square	.9660	.8423	2.3053	2.3319	1.8664	.4363	2.1178	.2011	2.0380	.6764	9.4271	.3058	23.3144
Sugar Beets	Observed	0	0	0	0	1	5	0	0	3	1	1	0	11
	Chi-square	.7908	.4862	.8117	.4663	.3733	7.0214	1.0747	.5884	2.3193	.6902	.0163	1.7247	16.3633
Asparagus	Observed	0	0	0	0	0	0	0	0	2	0	2	6	10
	Chi-square	.7190	.4420	.7379	.4240	.4979	1.4760	.9769	.5349	.6043	.4049	.9052	12.5271	20.2051
Grapes	Observed	0	1	30	0	0	0	5	6	0	0	1	0	43
	Chi-square	3.0917	.4267	226.7808	1.8232	2.1414	6.3468	.1519	5.9492	4.9965	1.7414	2.6670	6.7424	262.8590
Deciduous Fruit and Nut Crops	Observed	1	0	1	7	4	0	36	9	2	1	0	1	62
	Chi-square	2.6821	2.7404	2.7941	7.2684	.2696	9.1512	148.0105	9.7366	3.7596	.9092	6.4045	7.8244	201.5506
Pasture	Observed	0	4	6	0	3	3	6	5	5	4	2	2	40
	Chi-square	2.8760	2.8177	2.9519	1.6959	.5100	1.4283	1.1198	3.8222	.0266	3.4965	1.1000	2.9097	24.7546
Rangeland	Observed	0	18	0	3	5	2	0	0	0	0	0	0	28
	Chi-square	2.0132	227.0346	2.0663	2.7680	9.3232	1.1006	2.7355	1.4979	3.2535	1.1340	2.8924	4.3093	260.1285
Fallow Cropland	Observed	1	0	1	13	6	52	3	4	36	12	33	54	215
	Chi-square	13.5231	9.5029	13.9300	1.6548	2.0692	12.9422	15.4339	4.8935	4.8582	1.2449	5.2425	12.2093	97.5045
Urban	Observed	32	0	1	0	2	2	1	2	5	3	1	6	55
	Chi-square	198.9000	2.4310	2.3053	2.3319	.1993	4.6107	3.5595	.3018	.3027	.2679	3.8575	.7983	219.8659
Total	Observed	39	24	40	24	27	80	53	29	63	22	56	85	542
	Chi-square	226.6578	247.7404	256.3807	20.7650	17.2687	46.5127	177.4276	28.5560	24.8313	11.4969	32.6764	57.4984	1,147.8119

Theoretical Chi-Square (.05, 99d.f.) = 124.3
Calculated Chi-Square = 1,147.8

*Note that the overall calculated X^2 exceeds the theoretical value, thus implying that the distribution of land use/crop categories varies with stratum.

Since the X^2 value calculated from the contingency table exceeded the theoretical value (i.e., 1,147.8 > 124.3) it was concluded that interaction between strata and land use/crop type categories did exist. A comparison of the individual stratum X^2 totals with the distribution diagrams in Figure 2.4 gives an indication of the nature of the classification of each stratum. Those strata which had high calculated X^2 values (numbers 1, 3, 7, 11, and 16) were those that were dominated by one land use/crop type category (urban, rangeland, grapes, deciduous fruit and nuts, and fallow cropland, respectively). The remaining strata, having lower X^2 values, were composed of more heterogeneous distributions.

Upon receipt of the January imagery, the County was restratified (see Section 2.1.3). Each flight observation was assigned to one of the twenty-three strata as delineated on this imagery, and the data were organized into a contingency table. As was expected, the interaction between the January ground data and the strata delineated on the January imagery was significant (X^2 = 1,774). As with the previous analysis, those strata which had the highest calculated X^2 values (numbers 1, 7, 12, 18, and 23) were those dominated by a single land use/crop type category (urban, rangeland, deciduous fruit and nuts, fallow cropland, and grapes respectively). These data are presented in detail in Table 2.4.

Of particular interest was the fact that the stratum boundaries delineated on July, 1972 imagery proved to be meaningful as evaluated using ground data obtained in January, 1973 (although not all strata within the county were sampled). Thus it would seem that the strata boundaries probably do not shift appreciably throughout the year, although it would not be reasonable to use the data collected in January to classify the strata drawn in July, since most of the crop land which was fallow in January contained crops in July.

It was concluded that the method described above of collecting ground data for strata analysis is quite efficient. Not only can data pertaining to large areas be collected in a relatively short period of time, but since the data are point samples, they are rapidly reduced for statistical analysis. However, the following two improvements should be implemented.

1. In the central California area, the data should be collected as close to June 1 as possible. At this time nearly all fields will be planted, and those which are not can generally be expected to remain fallow for the rest of the year.

2. Since most agricultural field boundaries are oriented north-south or east-west, the flight lines used to collect data should not be oriented in cardinal directions in order to prevent the possibility of collecting a biased sample.

TABLE 2.4. CONTINGENCY TABLE OF X^2 VALUES AND FREQUENCY, BY STRATA, OF THE VARIOUS LAND USE/CROP TYPE CATEGORIES AS DELINEATED ON JANUARY ERTS-1 IMAGERY.

Category		Stratum 1	3	6	7	8	9	10	11	12	13	14
Cereal and Grain Crops	Observed	0	0	14	0	5	0	0	0	0	0	0
	Chi-square	1.598	1.050	18.382	2.237	18.292	.274	.228	.639	2.494	1.644	.686
Forage Crops	Observed	2	0	11	0	2	0	2	9	2	9	8
	Chi-square	.681	2.337	.027	4.979	.001	.610	4.381	40.357	2.663	7.800	27.511
Sugar Beets	Observed	1	0	9	0	0	0	2	0	0	0	0
	Chi-square	.000	.644	12.986	1.371	.560	.168	24.729	.392	1.651	1.007	.420
Asparagus	Observed	0	0	0	0	0	0	0	0	0	0	0
	Chi-square	.567	.373	1.669	.794	.324	.097	.081	.227	.956	.583	.243
Grapes	Observed	0	2	0	0	0	0	0	0	5	6	0
	Chi-square	2.268	.174	6.675	3.175	1.296	.389	.324	.907	.362	5.765	.972
Deciduous Fruit and Nut Crops	Observed	0	1	4	5	4	0	0	0	40	4	0
	Chi-square	3.660	.821	4.256	.003	1.742	.627	.523	1.464	185.515	.015	1.568
Pasture	Observed	0	8	7	4	5	0	0	0	6	7	1
	Chi-square	4.278	9.575	2.482	.641	2.671	.733	.611	1.711	.204	1.535	.379
Rangeland	Observed	0	10	0	29	0	6	0	0	0	0	2
	Chi-square	2.423	44.404	7.130	193.346	1.384	75.096	.346	.969	4.084	2.492	.891
Fallow Cropland	Observed	5	1	55	11	4	0	1	5	1	6	3
	Chi-square	4.739	6.520	8.029	2.658	1.495	2.191	.374	.003	15.967	3.887	1.121
Urban	Observed	27	1	3	0	0	0	0	0	3	4	1
	Chi-square	201.433	.426	3.554	4.041	1.649	.495	.412	1.155	.716	.358	.045
Total	Observed	35	23	103	49	20	6	5	14	59	36	15
	Chi-square	221.648	66.322	65.190	213.266	29.414	80.681	32.010	47.824	214.811	25.085	33.835

Category		Stratum 15	16	17	18	20	21	23	24	25	27	37	38	Total
Cereal and Grain Crops	Observed	0	1	0	0	2	0	0	0	0	0	0	9	31
	Chi-square	2.191	.342	1.141	2.968	.004	.411	.913	.276	.365	.502	1.141	53.616	151.592
Forage Crops	Observed	3	1	1	0	8	2	1	0	0	0	7	1	69
	Chi-square	.723	2.216	.934	6.605	3.263	1.288	.524	.610	.813	1.118	7.828	.241	117.510
Sugar Beets	Observed	5	1	0	1	0	0	0	0	0	0	0	0	19
	Chi-square	9.956	.008	.700	.369	1.175	.252	.560	.168	.224	.308	.700	.448	58.793
Asparagus	Observed	2	5	0	4	0	0	0	0	0	0	0	0	11
	Chi-square	1.922	30.201	.405	8.247	.680	.146	.324	.097	.130	.178	.405	.259	48.907
Grapes	Observed	0	0	0	0	5	0	17	4	5	0	0	0	44
	Chi-square	3.110	2.527	1.620	4.212	1.907	.583	190.286	33.540	38.743	.713	1.620	1.037	102.206
Deciduous Fruit and Nut Crops	Observed	5	0	0	0	0	1	1	0	1	2	2	1	71
	Chi-square	.000	4.078	2.614	6.797	4.392	.004	.569	.627	.032	.628	.144	.271	220.750
Pasture	Observed	8	0	0	0	17	0	1	1	1	8	5	4	83
	Chi-square	.775	4.767	3.056	7.946	27.425	1.100	.854	.097	.000	32.942	1.237	2.137	107.177
Rangeland	Observed	0	0	0	0	0	0	0	0	0	0	0	0	47
	Chi-square	3.323	2.700	1.730	4.499	2.907	.623	1.384	.415	.554	.761	1.730	1.108	354.300
Fallow Cropland	Observed	23	31	14	60	10	6	0	1	0	1	7	1	248
	Chi-square	1.706	19.709	2.596	55.379	1.859	2.239	7.305	.648	2.922	2.267	.497	4.015	148.125
Urban	Observed	2	0	10	0	0	0	0	0	1	0	4	0	56
	Chi-square	.969	3.216	30.562	5.361	3.464	.742	1.649	.495	.175	.907	1.022	1.320	264.966
Total	Observed	48	39	25	65	42	9	20	6	8	11	25	16	679
	Chi-square	24.675	69.764	45.359	102.382	47.077	7.388	204.369	36.971	43.958	40.323	17.125	104.450	1,773.925

Theoretical Chi-Square (.05, 198 d.f.) = 231.8
Calculated Chi-Square = 1,773.9

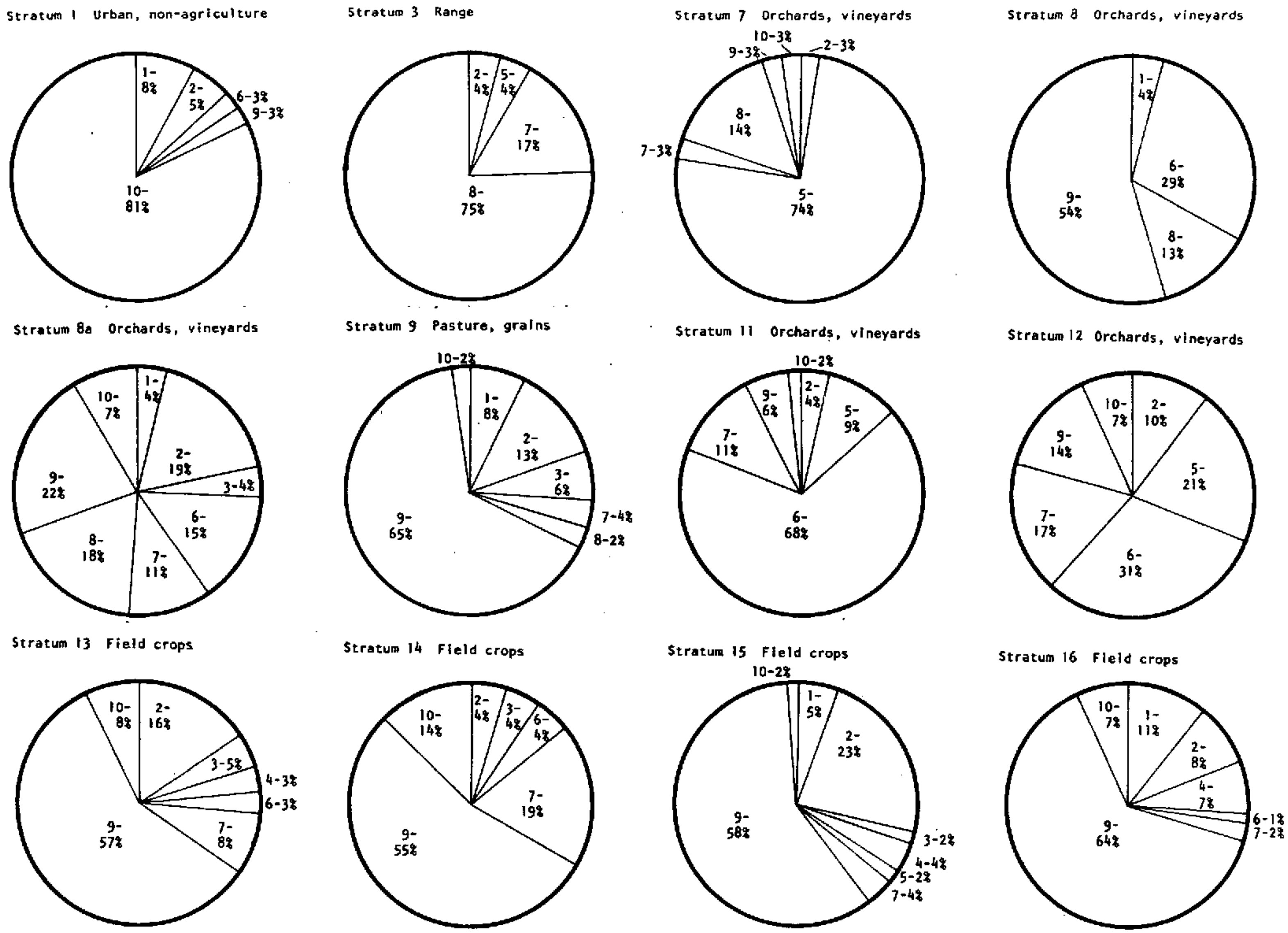


Figure 2.4. These diagrams describe, for each stratum, the proportion of each of ten land use/crop categories as ascertained by sampling from an aircraft flying the lines shown in Figure 2.3. The code of land use/crop categories is as follows: 1 = cereal and grain crops, 2 = forage crops (alfalfa, etc.), 3 = sugar beets, 4 = asparagus, 5 = grapes, 6 = fruit and nut crops, 7 = pasture, 8 = rangeland, 9 = fallow, 10 = urban -- non agricultural.

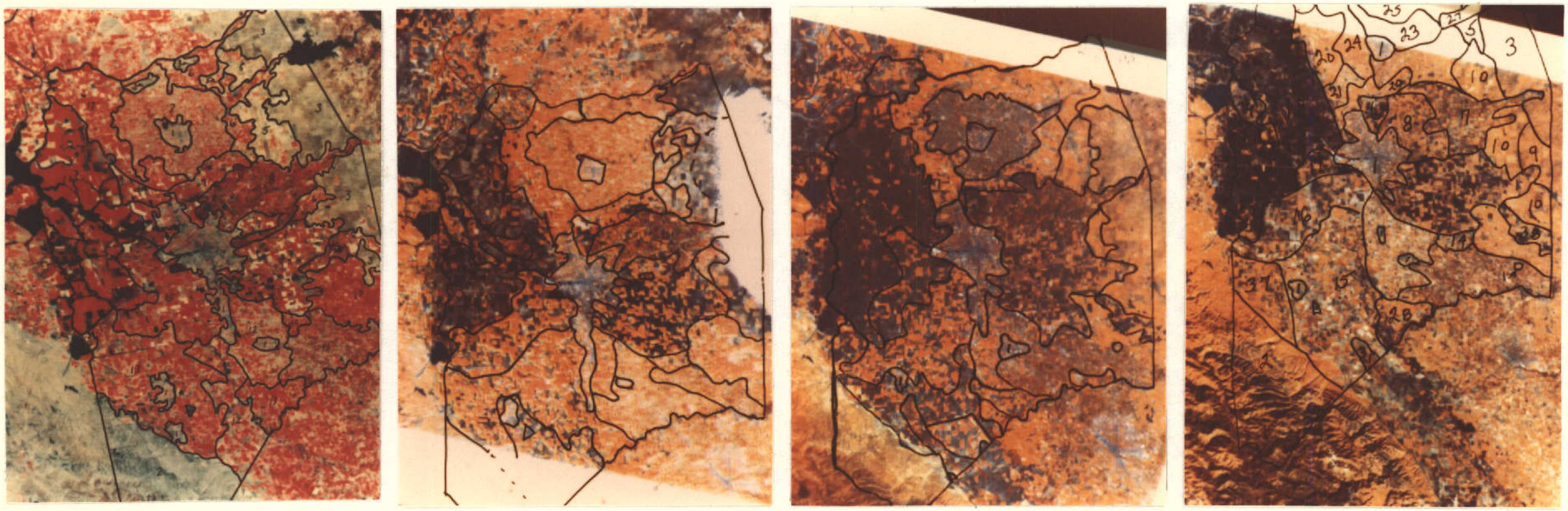
2.1.3 Seasonal Changes in Stratification Boundaries

Figure 2.5 illustrates the strata boundaries as drawn on ERTS-1 color composites acquired on July 26, 1972 (Summer); October 6, 1972 (Fall); January 4, 1972 (Winter); and May 10, 1973 (Spring). Table 2.5 briefly describes the appearance of six major land use strata as they appear on the various ERTS-1 color composites during the four seasons of the year.

Boundaries delineating urban-non agricultural areas remained relatively constant on all dates, although some variation occured during the spring months when recently seeded crops were germinating in agricultural fields and when ornamental urban plantings also were undergoing change. Vineyard areas were most easily delineated on the spring imagery since vegetation was readily apparent in adjacent field crop and dry land areas, but as yet not apparent in the deciduous vineyard areas. Vineyard areas, however could be delineated on all four images due to their fine texture and pattern, attributable mainly to their small field sizes. Orchard areas were easily delineated on all dates due to distinctive tonal and textural patterns, while Dryland areas were readily apparent on all except the spring imagery on which they were confused with field crop areas. Field crop areas were identifiable on all except the spring imagery when there was some confusion between them and dryland areas. Rangeland areas were identifiable during all four seasons, except that there was some confusion between them and dryland areas during the winter months.

It was concluded that, at least in the case of the particular test sites studied, ERTS-1 imagery can be of value in delineating major land use categories regardless of the date when the imagery was acquired. Certain catagories, such as dryland agriculture and vineyards, may be more easily delineated and identified in one particular season. The greatest differences in boundary placement from season to season occur within the field crop areas. On the July 1972 image, there appeared to be five field crop strata, whereas on the January image, there were seven. The strata boundaries as drawn on the July image were influenced primarily by differences in tone related to differences in crop type. The strata boundaries as drawn on the January image, however, were greatly influenced by differences in soil type which are more apparent in the winter due to the absence of vegetation in many areas. These soil differences were masked to some extent on the July image by the crop cover present during the summer season.

Thus it seems likely that the strata boundaries as drawn on the summer image are more meaningful in terms of land use differences as related to specific crop type. Hence it was concluded that the summer season stratification was the most useful for agricultural land use designations.



July 1972 October 1972 January 1973 May 1973

Figure 2.5. ERTS-1 MSS color composites of San Joaquin County, California. Images acquired at different seasons of the year were stratified to ascertain the extent to which agricultural land-use delineations varied depending on the date of image acquisition. It was concluded that in general the July (summer) image provided the most information regarding crop type distribution. See Table 2.2 for a description of the individual strata.

TABLE 2.5. DESCRIPTION OF APPEARANCE OF MAJOR LAND USE/CROP TYPE CATEGORIES ON ERTS-1 COLOR COMPOSITES TAKEN AT FOUR TIMES DURING THE GROWING SEASON.

Season	Urban or Non-Agriculture	Rangeland	Dryland Grain and Pasture Cultivation	Orchard	Vineyard	Field Crops
Summer (July)	Pinkish-gray w/ light blue linears. Fine texture. ●	Gray-brown. Smooth texture. ++	Buff, tan, gray, black areas. Coarse rectangular texture. ●	Purple to dark red. Medium rectangular texture. ●	Light red to dark salmon pink. Fine rectangular texture. +	Medium red, buff, gray and black. Coarse rectangular texture. ●
Fall (October)	More blue, less pink than in summer. Fine textured. ●	Dark gray. Smooth texture. ++	Light to dark gray. Coarse rectangular texture. ++	Dark red to purple. Medium rectangular texture. ●	Brownish-red. Fine rectangular texture. +	Red, gray, and black. Coarse rectangular texture. ++
Winter (January)	Blue gray with some red tones. Fine textured. +	Dark Gray to reddish orange. Smooth texture. - (confusion with dryland)	Dark to light reddish orange. Coarsely rectangular texture. - (confusion with rangeland)	Dark reddish brown. Medium rectangular texture. +	Light red. Fine texture. - (confusion with orchards)	Dark black, red and gray. Coarse rectangular texture. ++
Spring (May)	Red-orange to pink w/ light blue linears. Fine textured. +	Reddish-gray to reddish orange. Smooth texture. ●	Dark gray and light red to dark red. Coarse rectangular texture. - (confusion with field crops)	Purple to dark red. Medium rectangular texture. +	Dark gray. Medium rectangular texture. ●	Black, gray and red. Coarse rectangular textured. - (confusion with dryland crops)

● - Most detectable and delineatable
++ - Easily detectable and delineatable
\+ - Detectable
\- - Not always detectable and delineatable

Note: Color descriptions are based on appearance on diazo chrome enhancements and may vary slightly with exposure or development times or other methods of color enhancement.

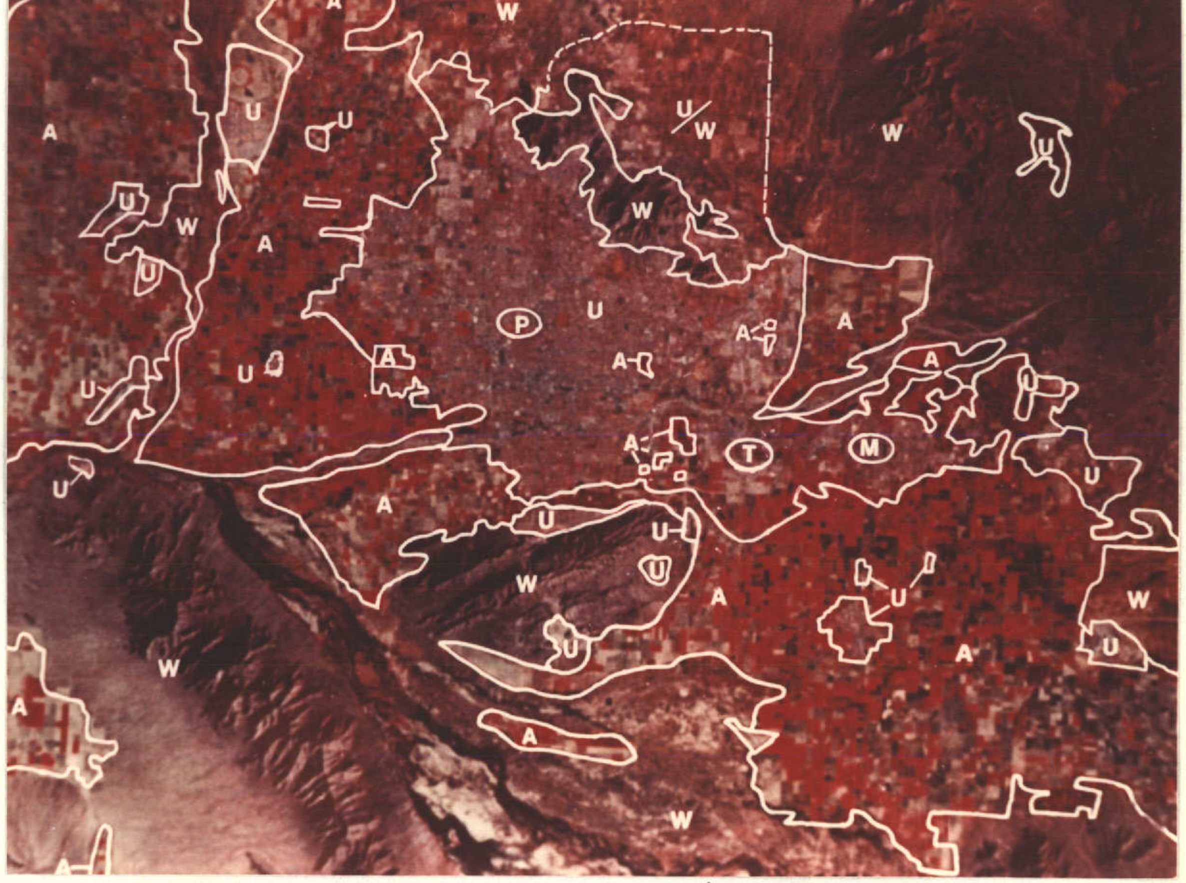
2.2 MONITORING CHANGES IN AGRICULTURAL LAND USE

One of the major areas of concern relating to agricultural resources is that of urban encroachment onto agricultural land. While at present there might appear to be adequate arable land in this country, population and urbanization trends indicate that some forethought should be given to the matter before it becomes a major problem. At the present time land allocation is monitored at irregular intervals, usually at the time of the population census, conducted every ten years.

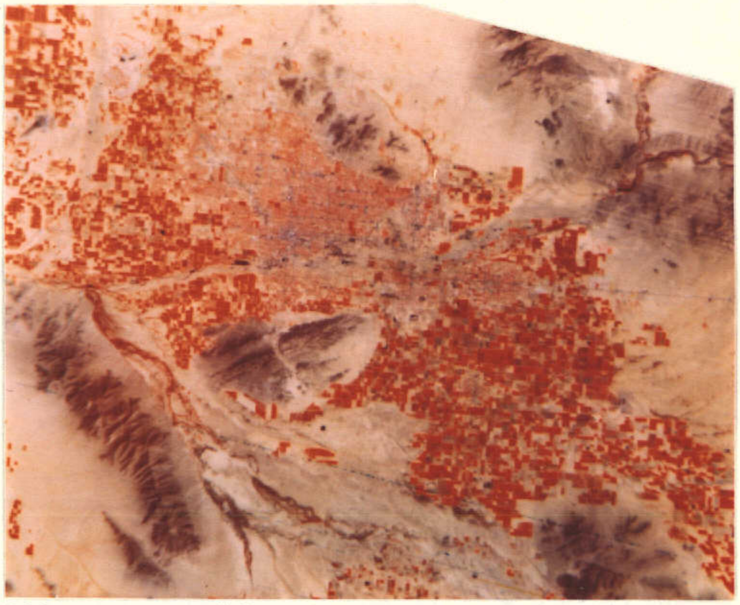
For this reason it was decided to test the feasibility of using satellite imagery with its possibility of more frequent coverage of areas of interest, and its synoptic characteristics which allow for the manipulation of less imagery, thus conserving time and resources needed for such a survey.

The area chosen for this feasibility experiment was Maricopa County, Arizona. This area is well suited for such a study in that it is one of the major leading agricultural counties in the country as well as one of the fastest growing counties in terms of population. The county contains approximately 300,000 acres of irrigated agricultural land. Much of this is concentrated in the Salt River Valley, which also contains the city of Phoenix. Along with its satellite urban areas, Phoenix is one of the most rapidly expanding population centers of the United States. The test area was photographed by both Apollo 9 (March 1969) and ERTS-1 (mid-summer 1972), providing an opportunity for an evaluation of the rate of urbanization of agricultural land in this part of the county during a 3-year period. For a selected part of the county, namely the agricultural and urban areas along the Salt River, shown in Figure 2.6, an enlargement of part of the Apollo 9 frame was produced. This enlargement has an approximate scale of 1:340,000. It was possible to delineate and identify most agricultural, wildland and urban areas greater than one square mile in area on this enlargement. The projection was interpreted and delineations were again made of the agricultural, wildland and urban areas. These delineations were transferred onto acetate material which was directly overlaid on the Apollo 9 enlargement such that changes in land use could be quickly identified. Since the prime interest in this study was to monitor land use shifts, either to or from agricultural use, only changes involving agricultural usage were quantified. With the use of a dot grid comprised at 100 dots/square inch, the acreage involved in each land shift was calculated.

For the Salt River Valley region of the county there were no apparent significant shifts of wildlands into agriculture during the period in question. All of the agricultural land shifts were to urban uses of various kinds, mostly urban residential useage. The total agricultural acreage shift into urban useage was approximately 28,000 acres. A breakdown of the total land use shift for the main incorporated urban areas in the Valley are as shown below:



(a.)



(b.)

Figure 2.6. Illustration (a) is an enlargement of a portion of the March 1969 Apollo 9 color infrared image covering Maricopa County, (Phoenix) Arizona. Delineations on the photo are of Urban (U), Agricultural (A), and Wildland (W) areas as interpreted from a portion of the ERTS-1 August 23, 1972 color composite illustrated in (b). The ERTS color composite was constructed using Diazochrome material. Magenta was used for Band 5, Cyan was used for Band 7, and Yellow was used for Band 4. The copies of these three ERTS bands were sandwiched together to simulate color infrared imagery. As can be seen in (a), areas displaying the greatest shift of agricultural land to urban use are south of the cities of Tempe (T), and Mesa (M), and southwest and northwest of Phoenix (P). The total acreage shifted from agricultural to urban usage as determined from analysis of these two dates of satellite imager was 28,160 acres.

Town or City	1969 Urbanized Area (Acres)	1972 Urbanized Area (Acres)	Amount of Agricultural Land (Acres) Lost
Chandler	1,920	2,880	960
Glendale	4,000	6,240	2,240
Mesa	8,320	13,440	5,120
Phoenix*	56,680	64,680	8,000
Scottsdale*	6,400	9,600	3,200
Tempe	7,200	15,840	8,640

*1972 urbanized area totals do not include sparse residential developments in wildland areas.

It can be calculated that during the last three years, an average of approximately 9,400 acres of agricultural land has been converted to urban use each year. In a recently published report of the Economic Research Service**, it was estimated that for the period from 1949 to 1964 Maricopa County had an average annual shift of all land into the urban category of 9,010 acres. Eighty percent of this figure was agricultural land being urbanized and thus the average annual shift of agricultural land to urban usage for the period of their study was 3,208 acres per year. From the study described above using the satellite imagery, it can be seen that the rate of urbanization of agricultural land in Maricopa County has tripled in recent years. Such dynamic situations need to be monitored more frequently and regularly than is presently done if adequate county planning is to be achieved. The results of this study indicate that satellite monitoring for evaluating rates of change of some situations is not only feasible but highly promising.

2.3 CROP INVENTORY TECHNIQUES

2.3.1 Manual Interpretation

In a study designed to evaluate the potential for manually identifying crop types on the ERTS-1 imagery for crop inventories, a survey of safflower fields in a portion of the San Joaquin County test site was carried out using human photo interpreters. In this case, the interpreters

**Dill, Jr., H.W. and R. C. Otte. 1970. "Urbanization of Lands in the Western States." U.S. Department of Agriculture Economic Research Service. January.

were trained by being shown a number of representative safflower fields on the July 26, 1972 ERTS-1 color composite image. They were then asked to note whether specific, indicated fields were safflower or not. For this test, approximately sixty fields were interpreted, of which thirty were safflower as ascertained by ground surveys. In addition, in a selected portion of the test area the interpreter was asked to delineate all safflower fields, thus necessitating not only an identification of the crop, but a determination of the field boundaries as well. Safflower was chosen as the subject crop for this test because it was passing through an "optimum" phenological stage for discrimination on the single date of ERTS-1 data initially available. By July, most safflower fields have matured to the dry state and appear light brown or tan on the color composite image as compared to the bright red of other maturing field crops, the blue-grey of bare soil, or the white of small grain stubble. Figure 2.7 illustrates several of the fields included in the identification test.

The identification test produced 83 percent correct identification. In the area where both detection and delineation were required, the formulas used and the results obtained were as follows:

$$\% \text{ Correct} = \frac{\# \text{ of fields correctly delineated as safflower}}{\text{total } \# \text{ of safflower fields in the test area}} \times 100 = 79\%$$

$$\% \text{ Commission Error} = \frac{\# \text{ of fields incorrectly delineated as safflower}}{\text{total } \# \text{ of safflower fields in the test area}} \times 100 = 4.6\%$$

Considering the fact that in this test the interpreters did not exploit the advantage of sequential coverage which ERTS-1 provides, these results were quite encouraging. Certainly they show that an interpreter can detect and delineate individual fields on the imagery. It was the general consensus of persons interpreting the ERTS-1 color composite that ground resolution for non-linear objects of medium contrast was on the order of 250 to 350 feet, and that it was possible to observe generally reliable signatures for fields down to 20 acres in size on the color composite.

However, in preparing to perform actual "operational" crop inventories on ERTS imagery, it is necessary to do more than merely ascertain what methods are best for identifying specific crops on the imagery. It also is necessary to solve the often overlooked practical problems of working with very large areas and designing techniques for combining "ground truth" data with satellite imagery. The solution of such problems is necessary for purposes of interpreter training, for the design of sampling and estimation procedures, and for purposes of evaluating the performance of the interpretation system.

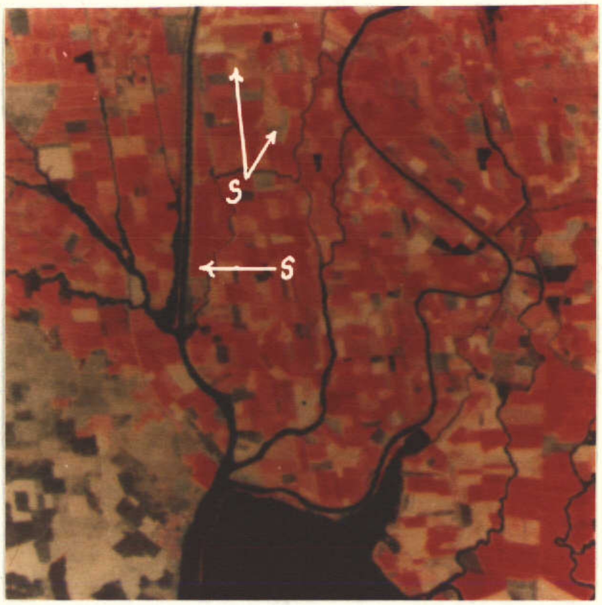


Figure 2.7. Three safflower fields, as they appear on the ERTS-1 color composite in the test area are indicated by the arrows. The upper two fields have matured and appear a characteristic light brown, while the lower field is immature and appears red, allowing it to be easily confused with other field crops in the area. The scale of this photo is approximately 1:340,000, or 5.4 miles to the inch.

To date, most of the identification and inventory of agricultural crops using ERTS-1 data have been done semi-automatically by computer analysis of digital tapes with human inputs of training materials. Although such systems have achieved very accurate results in certain test areas, there is still a need to develop techniques for manual interpretation of ERTS data for agricultural resource inventories. While computer-based systems may ultimately prove to be the most efficient method for gathering agricultural statistics pertaining to extensive areas, at the present time the human interpreter may represent the most expedient way to perform an operational inventory in the United States. For many of the emerging nations of the world, where both national agricultural statistics and computer systems may be nonexistent, the data gathered by human interpreters could provide a valuable input to the management decisions for agricultural resources.

In our attempt to develop efficient techniques for human interpretation of ERTS-1 imagery for crop inventories, it was apparent that several factors must be considered: (1) because of the large areal coverage of an ERTS image, 100 percent image interpretation of the entire frame for detailed information is not practical, (2) a simple method is needed to evaluate the accuracy of the interpreter's estimates and to adjust these estimates, if necessary, and (3) the low resolution of the imagery makes accurate acreage estimates by human interpreters impossible. In response to these requirements, an inventory technique using a double sampling design utilizing point data was developed. For the first stage (large sample) the interpreter is asked to determine the presence or absence of the crop of interest on a large number of points that have been distributed throughout the study area. These data are then used to estimate the proportion of the area that is planted to that particular crop. This proportion, when multiplied by the total area being inventoried will give an estimate of total crop acreage. The second stage consists of a subsample of the large sample. These subsample points are field checked, and the correlation between ground conditions and image interpretation estimates is used to evaluate interpreter accuracy and to calculate a ratio estimator to adjust the interpreter's estimated proportion.

It should be noted that this design can only be applied if the time from the satellite overpass to receipt of the data by the user is no longer than two weeks. Within this period of time the crop conditions on the ground should not have changed markedly from those imaged by the sensor, and a meaningful field check can be made. However, because of the lengthy time delay that now is experienced in obtaining ERTS-1 imagery, two alternatives in selecting the subsample can be used: (1) the large sample can be allocated on an ERTS image that was obtained at a date previous to that of the anticipated inventory, and the subsample can be selected and field checked at the time of the actual inventory, or (2) periodic crop data can be collected from permanent field plots that have been randomly distributed throughout the

inventory area, and those points from the large sample which fall within the permanent plots can thus represent the subsample. For operational inventories, the first alternative would be preferred because a large number of sample points can be field checked in a reasonably short period of time from low flying aircraft, and the expense of establishing and the need for visiting permanent field plots is avoided. On the other hand, the second alternative would be preferred if those performing the inventory had no previous knowledge of the crop development patterns within the area of interest, for the permanent plots would provide the additional information needed to determine the optimum periods for carrying out the inventory. While this technique has not been applied to an actual case study as yet, it is anticipated that a crop type inventory will be conducted in the near future using either ERTS-1 data acquired during the summer of 1973 or Skylab EREP photography.

2.3.2 Automatic Image Interpretation

Investigations regarding the application of automatic data processing of ERTS-1 data have focused on the San Joaquin County test site due primarily to: (1) the availability of monthly ground data, (2) the varied cropping and irrigation practices in the area, offering an excellent area for technique development, and (3) the accessibility of the site to the investigators.

The development of agricultural application techniques within the CRSR has progressed considerably during the past year. For example, in the initial ERTS-1 work, images of the four MSS bands from a single date were scanned using the CRSR scanning microdensitometer, the bands being registered using hard-copy line printer output. A 2 mile square test area was then classified using only training areas located within the test cell. The output consisted of a photograph of the color CRT display of the classification results. However, during the past year the capability has been developed to use ERTS data tapes to display areas on the 3-band CRT, select crop training areas using selected overlay grids, and apply the classifier to points within any specific irregular polygon. Thus it is possible to obtain point by point statistics from which statistically corrected acreages can be calculated, and to produce as output a photographic map of the results using either single or multiple date input data. A description of these projects and their results follows. For a detailed discussion of the hardware and software used, see Section 2.5 of this chapter.

2.3.2.1 Image Scanning Study

Of the forty-eight ground data cells in San Joaquin County, eleven cells in the field crop strata (as delineated by the photo interpreters in the stratification study described previously) were selected for intensive analysis.

Each cell was scanned on the transparency of the four MSS bands at a common scale and registration such that each data point represented a 250 x 250 foot spot on the ground. To accomplish this the map coordinates of the cells were entered in a program that computed the translation, rotation, and scale change necessary to place the map coordinates over the MSS images. This transformed coordinate information was then used by the scanner program to locate and scan the cells. Twenty-seven representative training areas were selected from the data to train the classification algorithm on the ten land use categories considered.

After the point-by-point classification was completed, each point was reclassified by an algorithm that considers the classification assigned to neighboring points. This technique improved the point-by-point classification between 10 and 30 percent depending on the homogeneity of the field. A field map of the ground truth was then laid over the final automatic classification results. Each field was then assigned to the class that had the maximum data point count within the field on the overlaid map (see Figure 2.8).

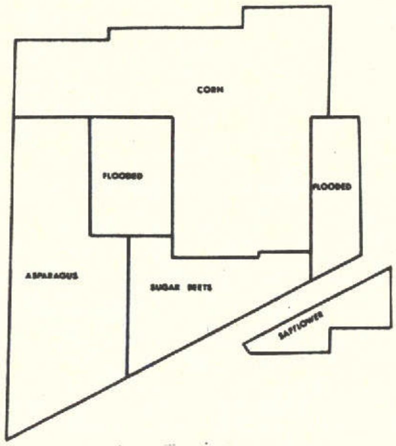
Table 2.6 summarizes the results of this classification, which resulted in an 84 percent overall correct identification. A total of 201 fields were classified in the test area. Again, these results are based on a field-by-field rather than a point-by-point identification, and are the result of an analysis of data from all four MSS bands. Use of the scanned photo data and pre-mapped field boundaries allowed classification down to a 20 acre field size. (The use of bulk-processed MSS computer compatible tapes should allow classification to a 10 acre minimum field size when the smallest side is 600 feet.) The poor results in classification of some crop classes was attributed to the small field size in relation to the image resolution. However, considering that the available imagery was acquired on a single, non-optimum date, these results are surprisingly good. and would suggest that more carefully controlled inventories will yield even better results.

2.3.2.2 ERTS Data Tape Study

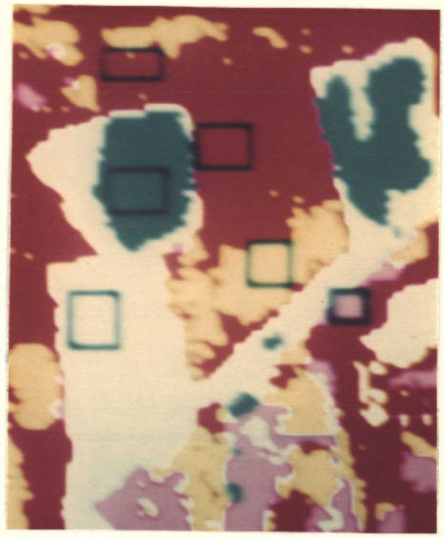
Several areas of San Joaquin County in the San Joaquin-Sacramento River Delta were chosen to test present classification techniques, and were extracted as matrices of 85 points by 85 lines. The computer was then "trained" for all known crop types and maturities, bare soil types and water in the following way:

The operator displayed the area on the color monitor, overlaid a grid which would accomodate the range in field size and shape, and using a ground truth map, attempted to locate areas of known crop type on the display; then he determined the coordinates of the resolution elements which represented those areas. Those groupings of test points or "fields" were then extracted onto another magnetic tape and the resulting data

Enlarged ERTS-1
color composite



Ground truth
map



Color display of
computer classification

Figure 2.8. One 4-square-mile ground data cell in the San Joaquin County test site is illustrated here as seen on (1) an enlargement of a portion of an ERTS-1 color composite image, (2) a "ground truth" map, and (3) a color display on the Forestry Remote Sensing Laboratory TV monitor of a computer classification of crop types.

TABLE 2.6. RESULTS OF CALSCAN CLASSIFICATION OF ERTS-1 DATA -- SAN JOAQUIN COUNTY, CALIFORNIA

RESULTS OF CALSCAN CLASSIFICATION
ERTS-I DATA - SAN JOAQUIN COUNTY, CALIFONIA

CLASSIFICATION RESULTS	GROUND DATA: SUNF	ASPA	CORN	SORG	WATR	NVEG	POTA	PLOW	SAFF	SUGB	TOTAL	COMMISSION ERROR
SUNF	4		1								5	20
ASPA	4	96	5				3	4	4	5	115	17
CORN	1	3	48				1				53	11
SORG										1	1	100
WATR		1			4						5	20
NVEG	1	1						1			3	100
POTA							2				2	0
PLOW		1					1	8			10	20
SAFF									5		5	0
SUGB										2	2	0
TOTAL	10	102	51	0	4	0	7	13	9	5		
%CORRECT	40	94	94	–	100	–	29	62	56	40		

TOTAL PERCENT CORRECT - 84.3

were processed by the CALSCAN program to determine the spectral statistics representative of each crop type for each of the four bands. The CALSCAN program was then used to classify each of the points in the 85 x 85 matrix (Figure 2.9c).

Because some of the individual elements were classified incorrectly due to irregularities in the crop, soil type, overlap in signature of two crops, or some other reason, the classification was then submitted to a process in which each point's reclassification depended not only on its own spectral likeness to the model of that crop, but also on the identity of its nearest neighbors. The result of this step was a very smooth pictorial output representing crop boundaries (Figure 2.9d).

It was expected that data from the tapes would lead to results superior to those resulting from the scanning of ERTS-1 images due to the elimination of the digital to analogue to digital step of creating an image and then scanning it to obtain a usable digital tape format to input into the CALSCAN program. The results obtained to date indicate that this is true. Anomalies not evident in the ERTS-1 images nor immediately evident in classification of the scanned data have appeared in the results from the tapes. A comparison with the RC-10 color infrared support photography from the U-2 missions indicates that these anomalies do in fact exist due to various factors such as poor crop growth, differential crop growth due to alluvial soil deposits on old river meanders, or different soil type backgrounds where crop cover is substantially less than 100 percent.

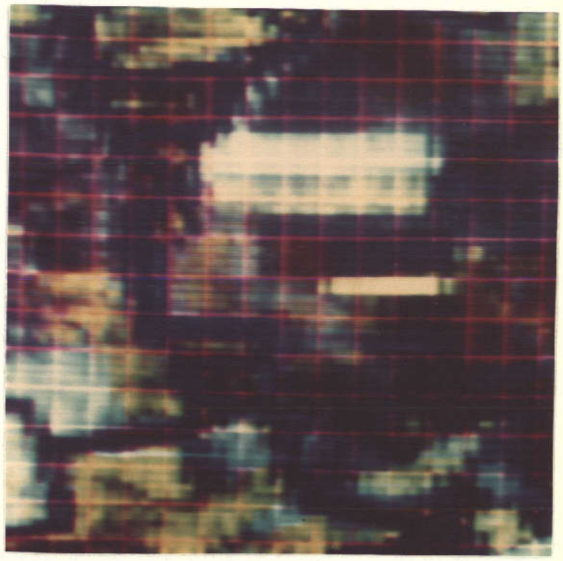
It now appears that the resolution is sufficiently good on the taped data that training techniques will need further sophistication, and that as a result, more information than was originally supposed may be derived.

2.3.2.3 Preliminary Large-Area Classifications

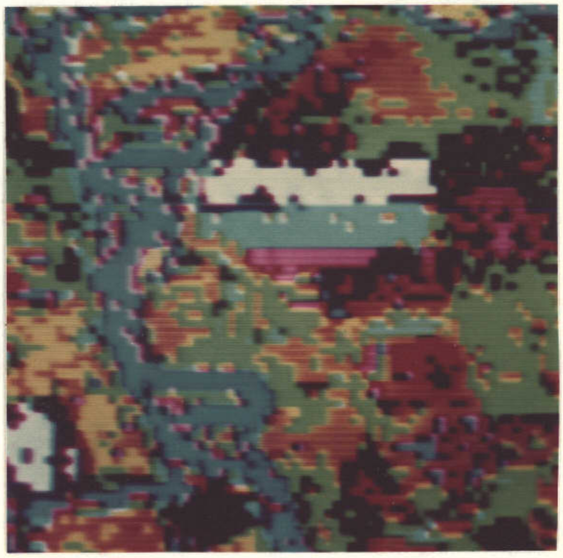
The classification of a large agricultural block on the west side of the San Joaquin County test site was next undertaken (1) as the natural subsequent step in an effort to show the capability of an automated data processing approach in producing accurate and timely agricultural inventories of larger areas and (2) as the next step in the automated analysis of human stratification of agricultural areas and of the relation of these strata to further automatic classification.

The area chosen is defined by points 411-810, lines 1000-1499 on ERTS tape 1003-18175-3/4. This area comprises approximately 340 square miles or 220,000 acres (Figure 2.10). It encompasses stratum 16 as delineated by CRSR's photo interpreters and, at the time of image acquisition, contained primarily field crops of which asparagus, corn, alfalfa and sugar beets comprised the majority. Of the forty-eight ground data cells maintained in San Joaquin County, four and most of a fifth are located within stratum 16. The support data used were collected

a



b



c

d

Figure 2.9.

a. Color infrared photograph of a portion of the San Joaquin test site acquired from the NASA-Ames U-2 aircraft with the Wild RC-10 camera. The approximate scale is 1 inch = 1.75 miles.

b. Color display of the area shown in a, as extracted from the July 26 ERTS-1 data tapes, wherein band 7 is displayed in red, band 6 in green, and band 5 in blue.

c. A color display of the same area, classified according to crop type by CALSCAN. Blue = water, green = asparagus, white = harvested barley (stubble), blue-green = potatoes, orange = sunflower, yellow = corn, magenta = harvested potatoes, black = bare soil.

d. A color display of the area, reclassified using weights by neighbors.

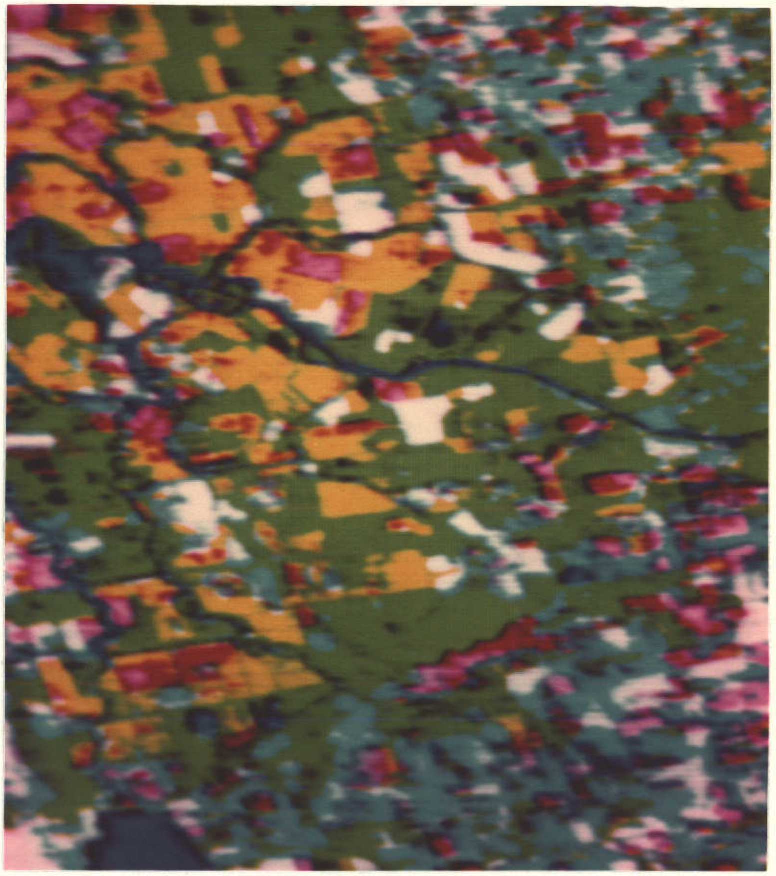


Figure 2.10. Photograph of an ERTS-1 "classification" display on the CRSR color CRT. This display, representing a 14.3 by 24.1 mile area of intensive agriculture in San Joaquin County, California is a map of the results of the classification of each point of data according to its spectral likeness to known crop types. The data used are from an ERTS-1 bulk MSS tape of July 26, 1972. The colors representing each crop type are listed below:

asparagus	= green	water	= blue
harvested	= white	potato	= rust
corn	= yellow	bare soil	= black
sugar beet	= red	tomato	= turquoise
safflower	= purple	alfalfa	= pink

in those cells within one day of the July 26, 1972 ERTS coverage on which the classification was done. The cells contained approximately 270 agricultural fields, averaging more than 40 acres each with a substantial variance in size. Several fields were omitted from the study because they contained crops that were not trained for in this stratum (e.g., sunflower and sorghum). By this process, 257 fields were subsequently classified and evaluated. The study was accomplished by training on 1340 acres, and testing on 11,000 acres. The study was accomplished by training on 1340 acres, and testing on 11,000 acres. The total area of the inventory was 219,872 acres.

Ten agricultural categories which comprised the majority of crops in the test area were included in 25 training fields. Those crops whose phenological stages varied at the time of the overflight were trained for each stage. Tomatoes and alfalfa were trained using data from a cell located in another stratum as none were contained in the cells in the study area. Statistical models were brought to a satisfactory level of training through repeating the "train, classify, evaluate, and retrain" cycle twice. The resulting improvement in performance was substantial although a quantitative measure of that improvement is not available. Each point in the area was then classified using an algorithm that computes a likelihood factor tha t the point is statistically similar to each training model and then assigns to the point the name of the category for which its factor is the highest. The area was then run through "reclassification" as described earlier. Quantitative evaluations were made of the point-by-point results in the training areas by a routine in the CALSCAN program and of the field by field results in the test cells by manually overlaying field maps and assigning to each field the crop indicated by a majority of its points.

The point by point evaluation of the training fields showed a class average of 87.8 percent correct for the "classified" results and 96.1 percent after "reclassification". The 8.3 percent gain is indicative of two things: (1) the reclassification according to weights-by-neighbors procedure, in cases where initial classification results are good, serves to correct anomalous points, and (2) a better selection of training points had been made using the "evaluate and retrain" process than in the previously described study wherein 10 to 30 percent gains by class were obtained. Subjectively, more accurate "classification" results are reflected in smoother, more homogeneous appearing fields on the color displays, even as compared with previously obtained "reclassified" displays. Furthermore, the previously described study used "reclassified data" to obtain an 84 percent correct result, whereas the results of this study were based solely on "classified" output. Reclassification, while it improved the appearance of the displays somewhat, did not substantially affect the results.

Table 2.7 lists the results of the study for the ten agricultural types considered. Overall, 88.3 percent of the fields in the test areas were correctly identified, some of which were as small as ten acres in size. The major crops in the test area were asparagus and corn which scored 89.4 and 92.2 percent correct respectively. It is significant that the largest errors resulted from a confusion of asparagus and bare soil. This difficulty was also encountered by ground observers due to the similarity in appearance of the two classes after cutting of the fern stage of the asparagus crop.

With the results from the test area as an indicator of the accuracy obtained, the classification of the entire test area was undertaken. Figure 2.10 illustrates the classified version of the test area as displayed on the FRSL color monitor. If the color display is compared with the boundary of stratum 16 as it appears in Figure 2.2, it is apparent that crop type and field size distribution are correlated with stratum boundaries.

The results of the total area classification in terms of acreage and percentage of crop type are shown in Table 2.8. The data presented there are essentially a quantitative description of the study area. The table lists the number of elements or points classified by CALSCAN as each crop type in the (1) "classified", (2) "reclassified", and (3) "reclassified with weights" versions of the display routine. Also shown are acreages and the percent of the total area occupied by each crop type, according to the "classified" results. In addition, the number of points, corresponding acreages and "percent of total area" values on which the test fields were scored are listed. Comparison of the "% of total" columns shows that the ground data cells in stratum 16 are quite representative of the area as a whole.

One area of further study would be quite valuable in providing additional data for Table 2.8. Systematic correlations should be made with "ground truth" data to determine the value of reclassification, with and without weights, in increasing result reliability and accuracy and the relationship between reclassified data and crop yield.

2.3.2.4 <u>Field Crop Inventories</u>

The work undertaken in Spring, 1973, was: (1) to apply classification techniques previously reported (Section 2.3.2.3) to other agricultural strata in the San Joaquin County test site to obtain statistics from which crop inventory acreages can be acquired; (2) to investigate the usefulness of automatic classification techniques in strata comprised of orchards, vineyards and pasture lands; and (3) to apply multidate techniques to individual field crop cells within the test site.

TABLE 2.7. FIELD BY FIELD RESULTS OF CLASSIFICATION OF TEST AREAS FROM ERTS-1 TAPE DATA

STRATUM 16 SAN JOAQUIN COUNTY, CALIFORNIA

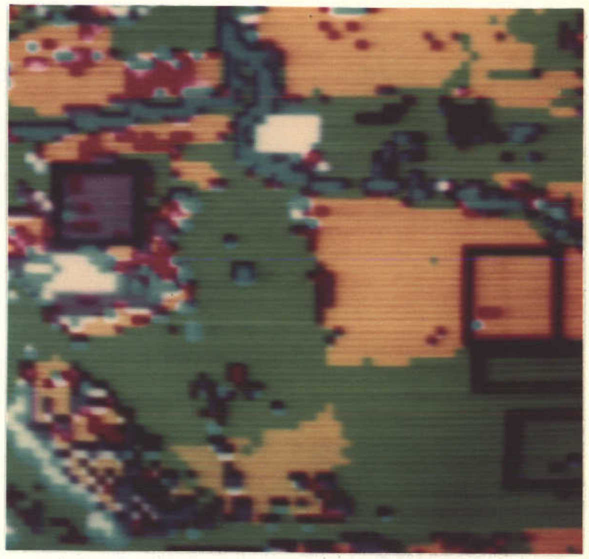
FIELD BY FIELD RESULTS OF CLASSIFICATION OF TEST AREAS FROM ERTS-1 TAPE DATA

STRATUM 16 SAN JOAQUIN COUNTY, CALIFORNIA

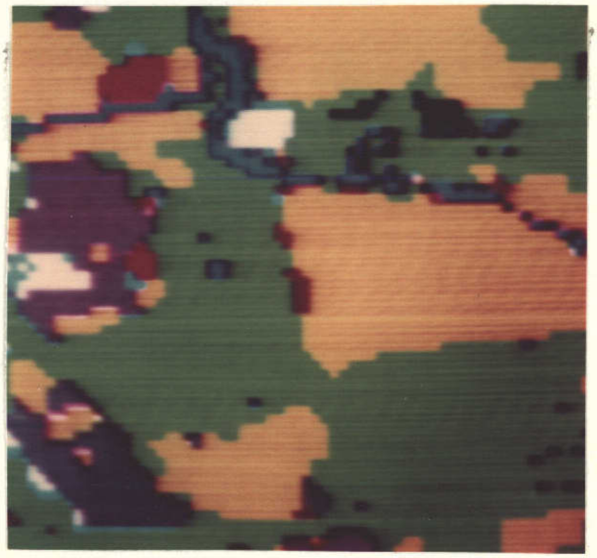
		GROUND DATA										TOTAL	COMMISSION ERROR
		ASPA	CORN	HARV	BARE SOIL	POTA	SAFF	SUG. BEET	FL. IRR.	ALFA	TOMA		
CLASSIFICATION	ASPA	126			4	3						133	5
	CORN	7	59									66	11
	HARV			19								19	0
	BARE SOIL	5			5							10	50
	POTA	2				4						6	35
	SAFF	1	1				6					8	25
	SUG. BEET		1			2		5				8	37
	FL. IRR.								3			3	0
	ALFA											0	—
	TOMA		3				1					4	100
TOTAL		141	64	19	9	9	7	5	3	0	0	257	
% CORRECT		89	92	100	56	44	86	100	100	—	—		227/257

TOTAL PERCENT CORRECT – 88.3

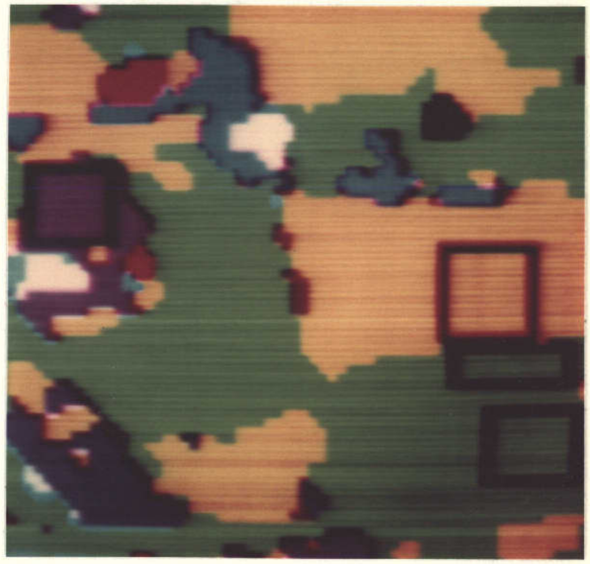
A



B



C



D

Figure 2.11. A test cell in the San Joaquin area displayed as: (A) color infrared photograph; (B) CALSCAN "classified" output; (C) "reclassified" output; and (D) "reclassified" output on which water and bare soil are not allowed to be reclassified. The improvement made in "classification" techniques can be seen when these photos are compared with those in Figure 2.9. Also apparent is the potential of reclassification routines for agricultural area mapping. Further study is planned on the use of "weighting" procedures for specific areas or land use types.

TABLE 2.8. POINT BY POINT RESULTS OF CLASSIFICATION OF ERTS-1 TAPE DATA, STRATUM 16, SAN JOAQUIN COUNTY, CALIFORNIA

	STUDY AREA					TEST EXTRACTIONS		
CROP TYPE	CLASSIFIED POINTS	RECLASSIFIED POINTS	RECLASSIFIED W/WEIGHTS	ACRES	% OF TOTAL	CLASSIFIED POINTS	ACRES	% OF TOTAL
ASPARAGUS	56,371	56,833	57,857	62,070	28.23	17,446	19,190	33.21
HARVESTED	32,103	31,282	30,416	35,377	16.09	5,159	5,675	9.83
CORN	26,662	31,320	31,290	29,375	13.36	8,720	9,592	16.60
SUGARBEET	15,646	14,689	15,046	17,238	7.84	4,309	4,740	8.20
SAFFLOWER	11,089	9,127	9,513	12,225	5.56	2,945	3,240	5.61
WATER	10,189	12,188	10,189	11,235	5.11	2,404	2,644	4.58
POTATO	5,749	3,022	3,137	6,332	2.88	1,866	2,053	3.55
BARE SOIL	1,450	973	1,450	1,583	.72	647	712	1.23
TOMATO	30,409	29,584	30,059	33,487	15.23	7,019	7,721	13.37
ALFALFA	9,932	10,582	10,643	10,950	4.98	1,994	2,193	3.80
TOTALS	199,600	199,600	199,600	219,872	100.00	52,509	57,760	99.98

The San Joaquin County test site contains seven strata in which field crops and grains are the major crops as described by CRSR photo interpreters (Table 2.2). As the method of training and testing are covered in the description of work on Stratum 16, only further work toward a county-wide crop inventory will be discussed here. The preliminary "train, classify and evaluate" cycle for strata 9, 14, 15, and 17, using July 26, 1972 ERTS-1 data has been completed and the results of all field crop classification testing are shown in Table 2.9. Training for the five strata was done using approximately 3180 acres of known crop types, and testing was accomplished on 615 fields averaging 40 acres each, amounting to a total of 24,600 acres. This training was then used to classify the 240,000 acres encompassed by these 5 strata. The results, showing a 78.0 percent correct classification score, are quite good considering the use of only one non-optimum date. Of the erroneous classifications, the confusion between asparagus and bare soil and that between asparagus and tomatoes, some of which had been harvested by that time, accounts for 21 percent. It is logical to assume from our previous work in Maricopa County, Arizona and elsewhere that the development of multidate capabilities and selection of better single dates will improve performance.

2.3.2.5 Orchard, Vineyard and Pastureland Classification

Preliminary investigation into the use of automatic classification techniques for the mapping and inventory of lands used for orchard, vineyard and pasture crops was initiated using single-date ERTS coverage of the San Joaquin County test site acquired on July 26, 1972. Two cells from Stratum 8 and one from Stratum 5 were selected for initial tests because the fields are relatively large and easy to locate for training and testing purposes.

Because inventory data are more useful and meaningful on an acreage basis than on a field-by-field basis, the acreages of classified fields were used to obtain areal results in addition to the field by field results shown. These acreage results tend to show gains in the percent correct evaluations because the automatic classifier generally does better on larger fields, probably due to more consistent cropping practices among larger growers.

STRATUM 5, CELL 15 -- Because the Stratum contains more crop types than this individual cell, other types were also trained using known fields in other cells contained within the stratum. Thus, the tables of results include a classification column labelled "other" (Table 2.10). As suspected, range and pasture lands are difficult to differentiate from each other. If they are combined into a single class, their field-by-field percent correct is 80 with the total for the entire cell up to 75.4. Evaluating this combination by acreage, the range-pasture classification is 84.4 percent correct.

TABLE 2.9. FIELD-BY-FIELD RESULTS OF CLASSIFYING FIELD CROP STRATA TEST AREAS OF SAN JOAQUIN COUNTY, CALIFORNIA USING JULY 26, 1972 ERTS-1 TAPE DATA

FIELDS CLASSIFIED AS:	GROUND DATA																							TOTAL	COMMISSION ERROR
	ASPA	SAFF	SUG BEET	ALFA	TOMA	WAL	CORN	HARV	BARE SOIL	PLOW	PAST	BURN	ROAD	WAT	GRAP	TREE	LIMA	RICE	PEP	SORG	SQUA	POTA	OTHER		
ASPARAGUS	132	1		4	1				4													3		145	7
SAFFLOWER	1	12					1																	14	10
SUGAR BEETS			30	2	4		1			1							5					2		45	31
ALFALFA	1	2	2	69	2						2							2						80	11
TOMATO	18	4	1	3	33		3	2									1				1			66	43
WALNUT						11	2										2		1					16	28
CORN	7						63																	70	9
HARVESTED					1			23			2							1						27	12
BARE SOIL	5								5															10	36
PLOWED	2			2				1		18	2				3				1					29	37
PASTURE				3		2					27						2		1					35	20
BURNED												1												1	0
ROAD				3									0											3	100
WATER														10										10	0
GRAPES								2							8			5						15	39
TREES														1		6								7	14
LIMA BEANS				1	1												10							12	9
RICE																		12						12	0
PEPPER																			1					1	0
SORGHUM				1																1				2	20
SQUASH																					1			1	0
POTATO	2																					4		6	18
OTHER				1	1															3			3	8	62
TOTAL	168	19	33	89	43	13	70	28	9	19	33	1	0	11	11	6	20	20	4	4	2	9	*	612	—
% CORRECT	79	63	91	78	77	85	90	82	55	95	82	100	—	91	73	100	50	60	25	25	50	44	*	—	%

TOTAL % CORRECT = 77.9

TABLE 2.10. CLASSIFICATION RESULTS, STRATUM 5, CELL 15

FIELD RESULTS

		GROUND DATA						TOTAL	COMMISSION ERROR
		RANGE	PASTURE	PLOWED	GRAPES	ALFALFA	BARLEY		
CLASSIFICATION	RANGE	16	7	1	1			25	30
	PASTURE	1	12					13	4
	PLOWED			5				5	0
	GRAPES	1			4			5	11
	ALFALFA		2		2	1	1	6	83
	BARLEY						0	0	0
	OTHER	3	3		1			7	100
TOTAL		21	24	6	8	1	1	61	
% CORRECT		76	50	83	50	100	0		38/61

TOTAL % CORRECT = 62.3

ACREAGE RESULTS

		GROUND DATA						TOTAL	COMMISSION ERROR
		RANGE	PASTURE	PLOWED	GRAPES	ALFALFA	BARLEY		
CLASSIFICATION	RANGE	845.3	150.4	17.1	62.9			1075.7	19
	PASTURE	8.8	247.4					256.2	2
	PLOWED			215.9				215.9	0
	GRAPES	20.2			192.8			213.0	6
	ALFALFA		43.6		30.8	37.0	14.3	125.7	71
	BARLEY						0	0	0
	OTHER	107.5	59.7		27.2			194.4	100
TOTAL		981.8	501.1	233.0	313.7	37.0	14.3	2080.9	
% CORRECT		86	49	93	61	100	0		1538.4/2080.9

TOTAL % CORRECT = 73.9

This degree of success in separating range and pasture from cultivated agriculture probably is adequate for some purposes but not for others. It is probable that additional research would lead to higher accuracy.

STRATUM 8, CELL 44 -- Again "other" types were trained which do not exist in this cell. The results (Table 2.11) indicate that the orchard crops, walnuts and deciduous fruit trees, are not well separated; e.g. six fields of walnut groves were classified as fruit trees. Combining these classes, however, allows orchards to be separated from all other crops with fair accuracy. On a field-by-field basis, the percent correct identification of a combined orchard class would be 100 with a reduction in the commission error to 22 percent. The overall classification accuracy of the entire cell would then be 72.3 percent. On an acreage basis, "orchard" would again be 100 percent correct, the commission error would be 34 percent and the cell overall would score 77.0 percent.

STRATUM 8, CELL 24 -- Cell 24 was trained for classes which do not exist within it, as were the other cells; however, it also contains classes which were not trained. This is significant because in this case the types not trained were orchard crops other than walnut. From the twenty-six fields of these "other" classes, twenty-one were classified as "other" types while only five were classified as walnut. This indicates a potential ability to separate orchard classes that needs further investigation. The results in this cell, then, counting only classes for which training exists, were 77.2 percent correct field-by-field and 77.7 percent correct (Table 2.12).

These tests of the performance of the automatic classifier in areas of mixed orchard, pasture and field cropping practices indicate the potential to separate the three major categories in areas where their mixing precludes human stratification. Further investigation should show whether more accurate determinations can be made within each of the categories, e.g., fruit trees vs. walnut trees, while classifying all three categories simultaneously, or whether the categories should be "stratified" as a result of preliminary classifcation and the specific crops then determined through a second classification. Due to high crop value and therefore intensive land use with small field sizes, further work needs to be done within orchard and vineyard areas to develop and evaluate inventory techniques.

2.3.2.6 Multidate Studies

At this time the application of multidate techniques using ERTS-1 tape data has proceeded only to the point of overlaying and registering data. The data can be displayed on the CRSR color monitor (Figure 2.12) for training and testing and then submitted to CALSCAN for classification. From the appearance of the enhancements displayed, it seems certain that success in the classification of ERTS data will parallel that of earlier CRSR work using automated classification techniques on high flight photography of Maricopa County, Arizona which was scanned in three

TABLE 2.11. CLASSIFICATION RESULTS, STRATUM 8, CELL 44

FIELD RESULTS

CLASSIFICATION	GROUND DATA: PLOWED	SORGHUM	SUGAR BEETS	ALFALFA	WALNUT	PASTURE	FRUIT TREES	BURNED	BEANS	HARVESTED	TOTAL	COMMISSION ERROR
PLOWED	1		1								2	50
SORGHUM		1				1					2	25
SUGAR BEETS			4	1		1					6	14
ALFALFA				9							9	0
WALNUT					4						4	0
PASTURE			1	1		0					2	50
FRUIT TREES		2	2		6		4				14	71
BURNED								5			5	0
BEANS									4		4	0
HARVESTED										1	1	0
OTHER			4						1		5	100
TOTAL	1	3	12	11	10	2	4	5	5	1	54	
%CORRECT	100	33	33	82	40	0	100	100	84	100		23/54

TOTAL % CORRECT = 61.1

ACREAGE RESULTS

CLASSIFICATION	GROUND DATA: PLOWED	SORGHUM	SUGAR BEETS	ALFALFA	WALNUT	PASTURE	FRUIT TREES	BURNED	BEANS	HARVESTED	TOTAL	COMMISSION ERROR
PLOWED	156.8		12.8								169.6	8
SORGHUM		84.4				20.0					104.4	12
SUGAR BEETS			540.4	11.2		15.2					566.8	3
ALFALFA				305.8							305.8	0
WALNUT					169.6						169.6	0
PASTURE			38.8	25.2		0					64.0	65
FRUIT TREES		68.0	138.4		136.6		93.0				436.0	79
BURNED								323.4			323.4	0
BEANS									74.0		74.0	0
HARVESTED										65.4	65.4	0
OTHER			208.0						41.6		249.6	100
TOTAL	156.8	152.4	938.4	342.2	306.2	35.2	93.0	323.4	115.6	65.4	2528.6	
%CORRECT	100	55	58	89	55	0	100	100	64	100		1812.8/2528.6

TOTAL % CORRECT = 71.7

TABLE 2.12. CLASSIFICATION RESULTS, STRATUM 8, CELL 24

FIELD RESULTS

		GROUND DATA								
		PLOWED	WALNUT	SUGAR BEET	CUCUMBER	PASTURE	TOMATO	OTHER		
CLASSIFICATION	PLOWED	1							1	0
	WALNUT		20					5	25	15
	SUGAR BEET			1					1	0
	CUCUMBER				1				1	0
	PASTURE					3			3	0
	TOMATO						1		1	0
	OTHER		8					21	29	100
TOTAL		1	28	1	1	3	1		35	
% CORRECT		100	71	100	100	100	100			27/35

TOTAL % CORRECT = 77.2

ACREAGE RESULTS

		GROUND DATA								
		PLOWED	WALNUT	SUGAR BEET	CUCUMBER	PASTURE	TOMATO	OTHER		
CLASSIFICATION	PLOWED	13.3							13.3	0
	WALNUT		330.5					50.7	381.2	10
	SUGAR BEET			2.6					2.6	0
	CUCUMBER				4.4				4.4	0
	PASTURE					19.5			19.5	0
	TOMATO						1.5		1.5	0
	OTHER		106.6					298.6	405.2	100
TOTAL		13.3	437.1	2.6	4.4	19.5	1.5	*	478.4	
% CORRECT		100	76	100	100	100	100	*		371.8/478.4

TOTAL % CORRECT = 77.7

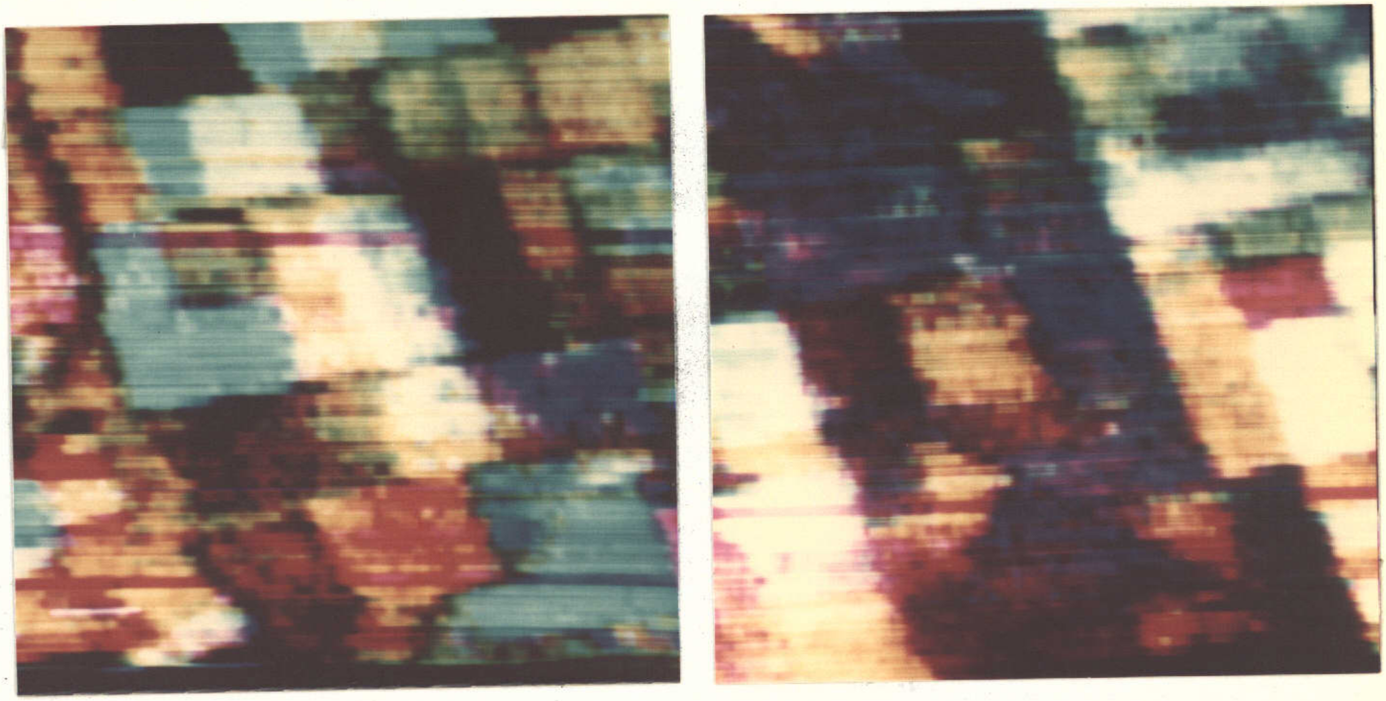


Figure 2.12. Multidate enhancements on CRSR color monitor showing (1) field delineations and (2) various distinguishable colors enabling classification.

TABLE 2.13. SUMMARY OF RESULTS OF MULTIDATE CLASSIFICATION OF CROPS USING RB-57 HIGH FLIGHT PHOTOGRAPHY OF THE MARICOPA COUNTY, ARIZONA TEST SITE.

Run #	Images* Used	Cell Classified	Training Cell	Divergence	Percent Correct	Per cell Cost of Run
1	7	1	1	213	60	2.60
2	7,11	1	1	413	100	3.80
3	7,11,12	1	1	695	100	5.43
4	1-12	1	1	*	97	21.80
5	1-12	3	3	*	91	21.80
6	1-12	2	2	*	91	21.80
7	1,3,4,6	1	1	534	87	7.46
8	1,3,4,6	3	3	643	80	7.46
9	1,3,4,6	2	2	443	66	7.46
10	1,3,4,6	1	2	*	13	7.46
11	1,4,4,6	3	2	*	18	7.46
12	1,3,4,6	3	1	*	78	7.46
13	1,3,4,6	2	1	*	17	7.46
14	1,4,7,10	1	1	694	97	7.46
15	2,4,8,11	2	2	*	93	7.46
16	3,6,9,12	3	3	*	95	7.46

*Image #'s refer to one of the three spectral bands on one of the four dates of photography as scanned on the CRSR microdensitometer.

bands. The previous work, done for the Earth Resources Survey Program of NASA, was reported in the "Analysis of Remote Sensing Data for Evaluating Vegetation Resources" on 30 September 1972. The results shown in Table 2.13 show that a classification accuracy of 90 to 100 percent should be obtainable using several combinations of bands with multidate techniques. Multidate tests will be completed for a supplementary report.

2.3.2.7 Conclusions

The results obtained working with ERTS-1 tape data for agricultural applications indicate that;

1. Field crop identification using data acquired on a single date can be accomplished to approximately 80 percent accuracy.

2. Areal statistics are obtainable through exploitation of the geometric quality of scanned data and identification of agricultural land use, combined with statistical analyses of classifier output using subsampling techniques.

Furthermore, the results suggest the probable positive value of continued research in:

1. Inventory techniques involving varied cropping situations.

2. Multidate data overlay, classification and evaluation.

3. Statistical subsampling techniques and applications.

4. Ground data collection methods for operational training and testing purposes.

2.4 PROPOSED SAMPLING PROCEDURES FOR AGRICULTURAL SURVEYS UTILIZING SPACECRAFT IMAGERY

In the recent past, discriminant analysis of remote sensing data has shown great potential as a tool for extracting resource information from the massive amounts of image data obtained from aircraft and spacecraft and especially the identification and mapping of agricultural crops. To date however, little has been done to optimize the training of the classifier, the processing of the data, or the sampling designs for projecting the results of the analysis. This discussion outlines a general ground data collection and sampling scheme that optimizes processing of remote sensing data and ground data. This scheme reduces the ground data needed because of information gained from remote sensing. In addition, an evaluation of the discriminant analysis procedure is shown, based on conditions encountered in the San Joaquin County test site in California.

In general there are two basic types of information required by resource managers: (1) an inventory or estimate of the quantity of the resource by administrative unit; or (2) an in-place mapping of the resource. Where a high correlation between the discriminant analysis estimate of the extent of the surface resources, and the ground estimates of the resource exists, unique and valuable information for meeting both requirements can be provided.

The models proposed here rely heavily in the first stage on the information extracted from the spacecraft data by both human and computer to provide the desired estimates. The second stage is based on low altitude aerial photography of sampling units selected using the satellite imagery. In some cases, where only surface area cover estimates are needed, the second stage imagery and the associated ground data are all the additional information needed. With other resources, where estimates of yield or volume per unit area of the resource are needed, three or more stages may be required to obtain adequate information.

2.4.1 Outline of the Procedure

The first stage of the model starts with the human stratification of spacecraft imagery. At this point, political and administrative boundaries may also be superimposed on the imagery to define the geographic area of interest. Next, to train the discriminant analysis program, fields identified by ground data or photo interpretation representing the various resource or vegetation types of interest in each stratum are located on small-scale photos for extraction from the digital tapes. The number of training fields required for each crop class depends on the variability of the spectral signature of the various crops present. This variability is caused by such factors as different cropping practices, local soil differences, and genetic variations within a particular crop type. For a crop such as alfalfa where there may be several stages of maturity present at the time of image acquisition, five or more fields per stratum may be required. In the case of less complex crop classes such as corn, one training example may be adequate. These training fields must also be large enough to be identifiable on the imagery acquired by the remote sensing system used in the first stage. On ERTS-1 imagery the minimum area is around 20 acres with a minimum dimension on one side of 800 feet. These fields are identified on and extracted from the spacecraft imagery and supplied as training to the discriminant analysis system. The multispectral data are then run through the discriminant analysis to obtain a point-by-point classification of the entire area by strata (as defined by the human interpreter). This provides an initial estimate of the acreage of the vegetation classes by strata.

The discriminant analysis results must then be sampled in some manner to determine the relationship between the discriminant analysis estimate and the true value or ground estimate of the resource. Sampling units (SUs) are then defined by breaking the entire area into rectangular areas which in the case of the ERTS study were based on the coordinate grid generated by the MSS system. The size and shape of each rectangular area are determined by the information requirements of the manager, the change in variability of the estimates for the SUs as their size is changed, the cost of making further estimates on the SUs, and the difficulty of recognizing the SUs on conventional larger-scale imagery.

At this point there are two basic models that can be applied, depending on which of the user requirements are most important. If an estimate of the quantity of a resource present is needed, and if it is found that the variance of the estimate is proportional to value of the resource,then probability sampling will generally be the most efficient model. If, however, inplace mapping is desired, a sampling scheme using regression estimation to establish the relationship between the discriminant analysis estimate and the ground estimate for the resource is used.

2.4.2 Probability Sampling Model

Probability sampling is a special case of the mean of the ratios estimation where samples are allocated proportional to the expected variance of the X_i estimate. For this model, the total value of the i^{th} SU, denoted by X_i, is evaluated by:

$$X_i = \sum_{m=1}^{M} \sum_{j=1}^{J} I_m V_j$$

where $I_m = 1$ if $C_m = j$

$I_m = 0$ otherwise

C_m = crop class for the m^{th} "pixel" (picture element) of the SU, as determined by the discriminant analysis,

M is the number of "pixels" per SU,

V_j is the crop class being evaluated

J = the number of crop classes.

The value or weight (v_j) is assigned to rank the various crops or vegetation types based on their relative importance to the survey. In an agricultural inventory where total dollar value is the objective, the v_j's would be the average dollar value per "pixel" of each of the crops (j). If an inventory of a single crop is the objective, the value of the crop of interest would be 1 and all other v_j's would be set to 0. In many cases this weighting factor would be primarily affected by the marketing conditions of each crop, and would be highest for those crops for which acreage estimate errors are most important.

The variance of the population is estimated by:

$$S^2 = \frac{1}{N-1} \sum (X_i - \overline{X})^2$$

The number (n) of SUs to be selected for photo and ground measurement when no remote sensing information is available is determined by:

$$n = \frac{Nt^2 s^2}{N(AE)^2 + t^2 s^2}$$

AE = the allowable error, in units of value t
t from "student's t" tables and
S^2 as defined previously

The n points are then selected from the list of SUs proportional to their estimated value.

The selected SUs are then carefully transferred to the corresponding high flight photography where precise field size measurements can be made for use later in adjusting the acreage estimates obtained from the classifier.

From high flight images, low altitude images, ground identification and historical data, the "correct" classification for each field in the SU is determined, down to crop type and maturity.

The total value for the area ($\hat{T}$) is estimated using the probability of selection (P_i) and the photo/ground estimate of SU value (Y_i) by:

$$\hat{T} = \frac{1}{n} \sum_{i=1}^{n} \frac{Y_i}{P_i}$$

$$P_i = \frac{X_i}{\sum_{i=1}^{N} X_i}$$

The variance of the estimate for $\hat{T}$ is

$$s_{\hat{T}}^2 = \mathrm{Var}(\hat{T}) = \frac{1}{n} \sum_{i=1}^{N} P_i \left(\frac{Y_i}{P_i} - \hat{T}\right)^2$$

If the photo/ground estimate (Y_i) were perfectly proportional to the remote sensing estimate (X_i), only one ground sample would be needed to determine the proportionality constant. More realistically however, the number of ground samples (n) for future surveys would be estimated by:

$$n = \frac{Nt^2 \, s_{\hat{T}}^2}{N(AE)^2 + t^2 \, s_{\hat{T}}^2}$$

This probability sampling model is appropriate where a single parameter such as, acreage of a single crop, value of all the crops present, or demand for irrigation water is desired. It can be replaced by a regression sampling model if estimates on a crop-by-crop basis are required, however the regression sampling model will only meet the allowable error criteria for the total value of all crops by strata.

2.4.3 Regression Sampling Model

The model for unit-by-unit estimates of all crops and land uses requires a random sampling design and thus cannot take advantage of optimal allocation of samples provided by probability sampling. It can, however, take advantage of the correlation between the remote sensing estimate and the ground estimate to reduce the sample size as compared with that required for simple random sampling (SRS).

Three possible regression estimators of the acreages for each crop class (j) can be used to adjust the multispectral scanner discriminant analysis estimates of the land use acreages.

1. If the relationship is linear but does not pass through the origin and the variance of Y_j is homogeneous, a regression estimator of the following form can be used:

$$Y_j = \overline{Y}_j + \beta (X_j^* - X_i)$$

where $\overline{Y}_j$ is the mean of the photo/ground estimates, X_j^* is the population mean of the corresponding remote sensing estimates and $\overline{X}_j$ is the mean of the remote sensing estimate for all the SUs.

2. The "Ratio of the means estimator" is appropriate when the relationship between Y_{ij} (photo/ground estimate) and X_{ij} (discriminant analysis estimate) is a straight line passing through the origin and Var (Y_{ij}) is proportional to $\hat{X}_{ij}$ $(=\sum x_i)$

$$Y_j = X_j \frac{\sum_{i=1}^{n} Y_{ij}}{\sum_{i=1}^{n} X_{ij}} \quad \text{and } X_j = \sum_{i=1}^{N} X_i$$

3. The "Mean of the ratio's estimator" is appropriate when the relationship between X_{ij} and Y_{ij} is a straight line passing through the origin, and if Var (Y_{ij}) is proportional to X_{ij}^2 for any given X_{ij}.

$$Y_j = \frac{X_j}{n} \sum_{i=1}^{n} \frac{Y_{ij}}{\hat{X}_{ij}}$$

If the X_i's are fixed, an estimate of the variance of

$$V(\overline{Y}|X_i) = \frac{S_e^2}{n} \quad 1 + \frac{n(X^* - \overline{X})^2}{(X_i - \overline{X})^2}$$

where S_e^2 is assumed the same for all X (homogeneous variance).

Because the entire population of X_i's is known from the discriminant analysis, the mean $\overline{X}$ is available and a stratified sampling scheme can be devised such that

$$X_j^* - \overline{X}_j \leq e$$

where e is chosen such that,

$$\frac{(X^* - \overline{X})^2}{\sum (X_i - \overline{X})^2} \quad \text{is small in relation to } S_e^2\text{, then}$$

$$\text{Var } (Y_j|X_i) = \frac{S_e^2}{n}$$

From this the sample size for a finite population can be determined by:

$$n = \frac{NSe^2\ t^2}{N(AE)^2 + S_e^2\ t^2}$$

This provides an estimate for n based on the overall variability of the remote sensing estimate (X_i) around the ground estimate (Y_i) for all classes. If, however, we have to meet a predetermined precision level for a certain crop class, then n is determined by

$$n = \max n_j = \frac{N\ t^2\ S_{ej}^{\ 2}}{N(AE_j)^2 + t^2\ S_{ej}^{\ 2}}$$

$$\text{where } S_{ej}^{\ 2} = \frac{1}{n} \sum_{i=1}^{n} (X_{ij} - Y_{ij})^2$$

If the allowable error is applied to the "worst case" estimate, the n would be computed for all j's and the maximum n_j would be used as n.

Estimates of $S_e^{\ 2}$ and $S_{ej}^{\ 2}$'s may be available from previous inventories based on the same remote sensing system and land use types, or by using a two step inventory where a small number of initial samples are taken to estimate $S_e^{\ 2}$ or $S_{ej}^{\ 2}$'s.

2.4.4 Evaluation of Discriminant Analysis

To evaluate the relative utility of the discriminant analysis of ERTS-1 multispectral-multidate imagery in estimating the area of agricultural crops the information obtained from the discriminant analysis, ground data and high flight imagery of the intensive test site in San Joaquin County was used to determine the optimum size of the sampling unit and the number of samples required to obtain acceptable estimates of crop area for the entire county.

The optimum size of the primary (first stage) sampling unit was found to be 25 x 35 picture elements (equivalent to 386 hectares on the ground). This was determined from the estimates of the coefficient of variation, as shown in Figure 2.13 and the plot of expected error in transferring the ERTS SUs to the corresponding photography for precise area measurement (Figure 2.14).

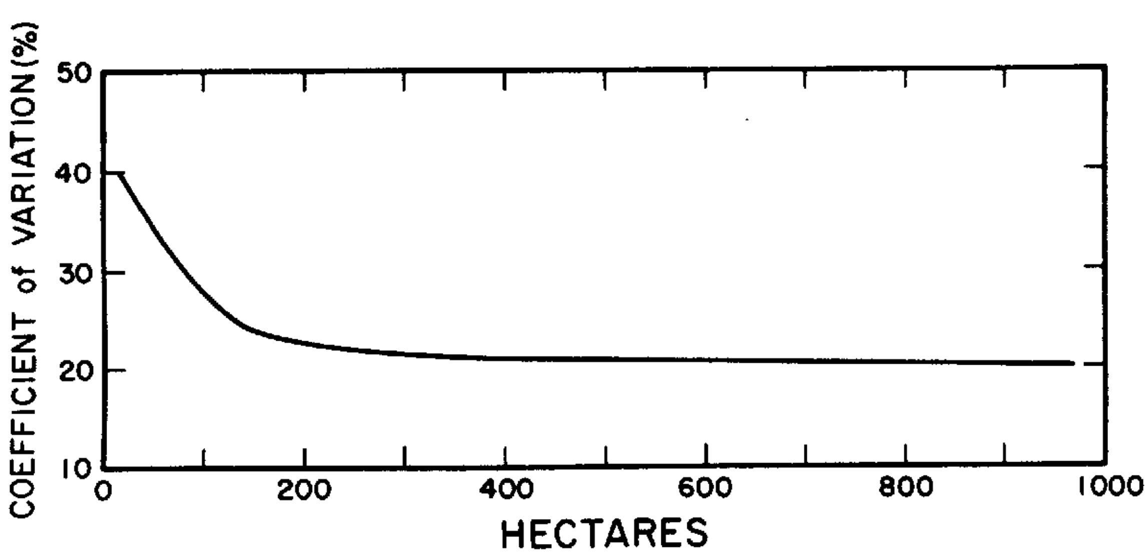


Figure 2.13. This plot of the coefficient of variation of the crop value obtained from the discriminant analysis of ERTS-1 data versus the size of the sampling units was used to determine the optimum SU size.

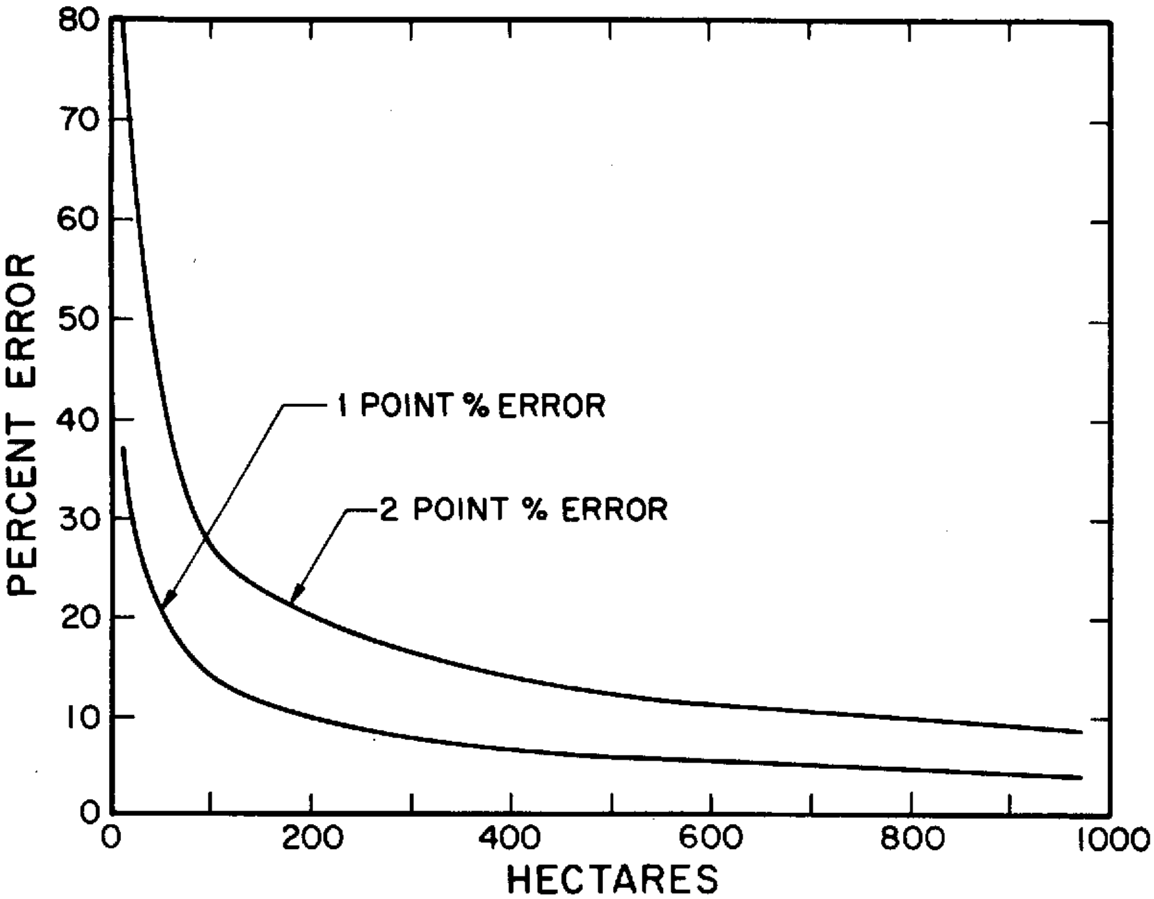


Figure 2.14. This plot of the expected error in transferring the sampling unit (SU) to the aircraft photography for further field size measurements was used in determining the optimum SU size.

Based on the information obtained from ERTS-1 discriminant analysis and human stratification of the area, the number of samples required for the probability sampling scheme was determined by

$$n = \frac{N\, t^2\, S_e{}^2}{N(AE) + t^2 (S_e)^2}$$

using several combinations of this information:

(1) Human stratification
(2) Human stratification and discriminant analysis on one date
(3) Human stratification and discriminant analysis on two dates
(4) Human stratification and discriminant analysis on three dates
(5) Discriminant analysis only

The $(S_e)^2$ was computed for single and multi-date discriminant analysis estimates. For crop classes where harvesting had taken place prior to or shortly after the ERTS-1 launch, estimates of $(S_e)^2$ were based on previous results from multispectral photographs and multispectral scanner studies.

The estimates of n were based on an allowable error of $\pm$ 5 percent at 95 percent level of confidence.

An estimate of the cost of a survey (Table 2.14) was made, based on the sample size required, the estimated cost of the processing of the ERTS-1 data, and the subsequent cost of processing the selected SU. The costs given are estimates, used here to demonstrate the relative utility of each of the information inputs from the human and computer analyses of the ERTS data.

2.4.5 Conclusions

The plot of relative costs (Figure 2.15) of a crop inventory indicates that neither completely automatic or completely manual methods are efficient, whereas a combined manual-automatic effort provides a more cost-effective alternative. This least-cost point is a result of the reductions in computer costs due to the human stratification, reduction in the number of ground samples required, and increased computer cost as the number of dates used increases. Computer costs are reduced significantly by reducing the number of classes to be considered during automatic point-by-point classification. If, for example, forty classes exist over the entire study area but through stratification only eight classes are considered for each point using ten strata, a four to one reduction in computer costs would be realized.

TABLE 2.14. ESTIMATED COSTS OF A CROP INVENTORY SURVEY USING VARIOUS INFORMATION INPUTS.

	STRATIFIED NO CALSCAN	MULTI DATE CALSCAN			CALSCAN NO STRATIFICATION
		ONE DATE	TWO DATES	THREE DATES	
STRATIFICATION	120	120	120	120	0
TRAINING EXTRACTION	0	660	660	660	1370
CALSCAN ANALYSIS	0	210	570	1176	8260
SAMPLING GROUND ENUMERATION and CALCULATION	n=82 8835	n=22 2430	n=11 1275	n=9 1060	8835
TOTAL COST	8955	3420	2625	3021	18,465
RELATIVE COST	1.0	.38	.29	.34	2.06

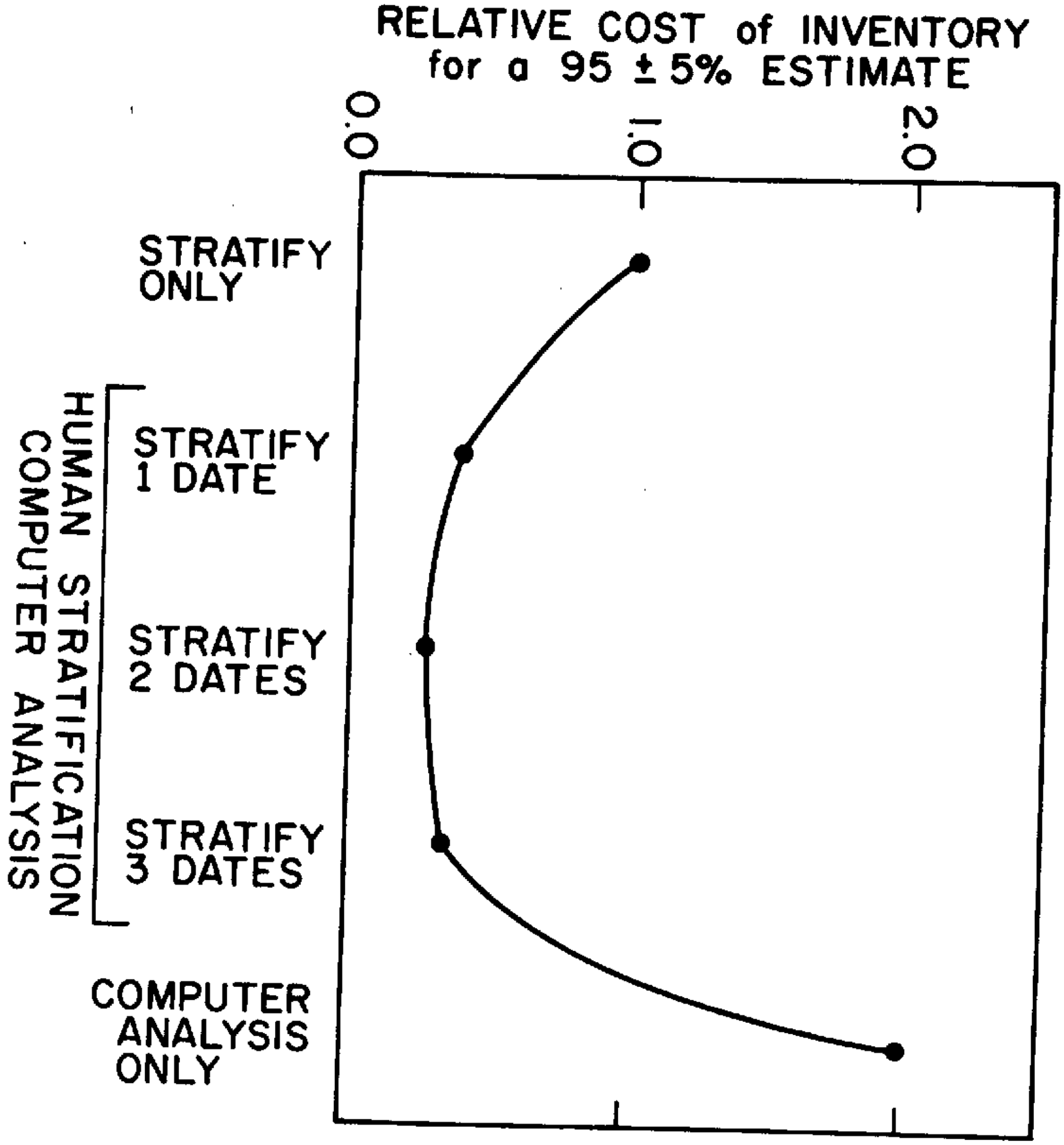


Figure 2.15. This plot illustrates estimated relative costs of performing a crop inventory in the San Joaquin County test area using various information inputs, with an accuracy of ± 5 percent at the 95 percent confidence level.

A second source of saving is the elimination of areas from automatic classification by interpreter delineation when the human can adequately specify the land use or that the area is not of interest to the resource manager. This saving is nearly one to one for each point eliminated, but the saving is reduced by the computational overhead needed to determine the point-by-point strata assignment. The number of ground samples is reduced because the classification accuracy is increased significantly by separating, through stratification, classes that have spectral signatures so similar that they cannot be separated by the discriminant analysis routine. The sample size (n) is further reduced by the additional information obtained from the multidate discriminant analysis.

2.5 AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING SYSTEM

A substantial part of the effort of the CRSR in investigating potential applications of ERTS data consisted of the development of a number of basic data handling and analysis capabilities. Particularly in the area of automatic interpretation and data processing, a unique and inovative system of hardware and software has been developed. The results of the applications studies themselves have been discussed earlier in this chapter. The following is a more detailed discussion of the actual data processing system. While much of the system has been developed for work with ERTS data, in most cases the components of the system can be used in the processing of a wide variety of basic data inputs.

2.5.1 General Processing and Data Flow

Four major classes of computer programs have been assembled for use on the CRSR computer and the associated large scale computers at the University of California and Lawrence Berkeley Laboratory: (1) Digital image handling and display, (2) Statistical spatial and spectral pattern recognition, (3) Mapping and multilevel data bank("MAPIT")and (4) General statistical analysis. These programs are being used to process the data obtained from the ERTS package, Skylab, manned aircraft and ground collection. They allow the selection and reformatting of selected areas that are analyzed intensively for correlation with ground data, mapping of features of interest based on their spatial and spectral characteristics, selection of optimum dates and spectral band(s) for classification, and comparison with existing data, both mapped and point. They are also used to compare manually mapped boundaries and computer generated boundaries with ground data.

Figure 2.16 depicts the way that the various software components are linked together to provide a system of software and hardware for the processing of remote sensing data from both aircraft and spacecraft. Each of the steps depicted in the flow chart is described in detail in the text that follows.

Flow Chart Depicting the Interactive Processing of ERTS Digital Images

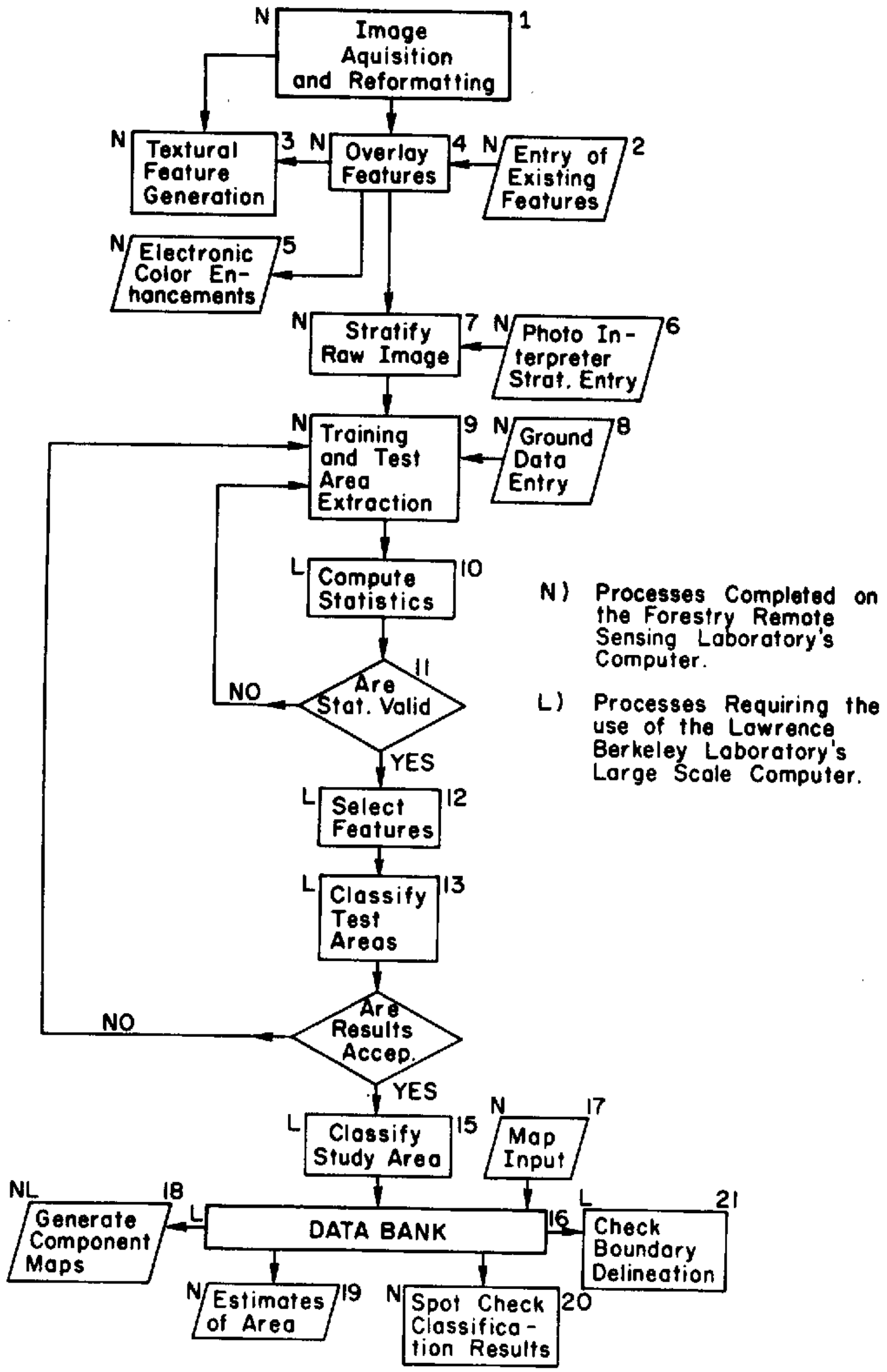


Figure 2.16. Flow chart depicting the interactive processing of ERTS digital images.

a. Image acquisition and reformatting: The digital equivalent of imagery from both spacecraft and aircraft enters the processing system at this point. It can be from multispectral scanners or photography. Before the digital tapes can be used efficiently on the local system they must be reformatted to local specifications. This is done on the CRSR computer to minimize computing cost. At this point, the tapes necessary to cover the study area are selected, and those portions not needed because of overlapping coverage are eliminated. Coordinate information is placed in a library to be used in later stages of the processing. When the image source is photography, it is scanned and stored on digital magnetic tape. Both black-and-white and color imagery can be used in the system.

b. Entry of existing features: Features such as topography, rainfall, earlier imagery and water availability are entered at this point if they will aid in the discrimination of the classes of interest. They can be entered manually with the digitizing equipment, qutomatically through the scanning microdensitometer, or from existing digital tape data.

c. Textural feature generation: Software has been developed to quantify the spatial frequencey characteristic of the area surrounding a given picture element. This step is used only when insufficient information is available from the spectral data to make the desired discrimination, or when the spatial information is more cost effective than the spectral information.

d. Overlay features: The images of features coming from steps 1-3 are put in common register and written on magnetic tape in the format used by the display and classification programs at later steps.

e. Enhancement and display: Here the CRSR computer display is used to combine features and transform the data to increase the apparent information content of the image to the photo interpreter. The current enhancement programs include multiband false color which can be generated from ratios, differentials, nonlinear transforms and density slicing. These procedures allow easier photo interpreter discrimination of edges, tones and textures of classes that are of interest.

f. Photo interpreter stratification entry: Because a human usually has a greater ability than a machine to recognize and delineate the boundaries between general land classes such as agriculture, rock, desert, grassland, woody vegetation, and urban areas, and sometimes even to further break these classes down by their textural and tonal characteristics, this step in the processing has been provided to allow the incorporation of such data into the automatic classification process. The strata data can be entered through the coordinate digitizer by the interpreter at the time of delineation to minimize the effort required to get the data into the system. Irregular political and administrative boundaries are also entered at this point to restrict processing to the area of interest at later steps.

g. Stratification of raw image: The data entered by the photo interpreter from step 6 are put in common register with the multi-feature images from step 4. This allows the automatic classification to be done on individual strata or logical combinations of strata to eliminate the anomalies that occur between classes that are easily separated by photo interpreters. Results from ERTS-1 indicate that this stratification increases the accuracy of the resultant combined classification significantly and reduces the computing cost by eliminating large areas that do not need the detailed classification provided by the automatic classifier.

h. Ground data entry: Through the use of a display/light pen, a coordinate digitizer and a photo comparator, the information obtained from ground visits, high flight photography and low altitude photography is entered into the system. This information is used at several points in the processing to train the classifier and to check classification results.

i. Training and test area extraction: Here the ground data are used to extract selected training and test areas from the raw stratified data images that have been created through previous processing steps. If at points further along in the processing it is found that the training is inaccurate or inadequate, the processing returns to this point to allow retraining of the classifier.

j. Compute statistics: The raw data from the training areas are reduced to the statistics necessary to determine the separability of the classes, select the features to be used in the classifier and generate the discriminant function in the classifier.

k. Are statistics valid? At this interactive point in the processing the statistics generated in the previous step are used to check the validity of the training set. If the data statistics seem adequate the processing is continued; otherwise the control is returned to step 9 where new training areas are defined to eliminate the deficiencies in the original set.

l. Feature selection: Once the training set has been defined the optimum set of features is selected for use in the discriminant function. Because of the geometric rate of increase in the cost of adding features to the discriminant analysis, and also because of the need to satisfy the requirements of the user, the choice of the number and type of features is very important to the cost-effectiveness of the automatic classification techniques.

m. Classify test areas: The features and statistics from the previous steps are applied to the intensive test areas and point-by-point maximum likelihood discrimination is made. Thresholds can be applied to minimize the incorrect classification of classes not represented in the training set. A second level of classification can be made at this point by applying and algorithm that uses the results of the point-by-point classification and the spatial and spectral relationship of neighboring points to assign a final class to each point. This is used to eliminate classification errors that occur due to spectral errors from points that fall on field boundaries in agricultural areas or on vegetation type boundaries in the wildland areas.

n. Are the results acceptable? Through use of the ground data entered earlier, the results of the point by point classification are checked on an area basis. This check can be done either manually or automatically by overlaying the precision digitized coordinates of the area boundaries from the high flight photography on the output of the classifier and applying the ground data to these fields. The summarized data are checked to determine whether the results of the classification meet the requirements of the user. If not, processing is returned to step 9 for further training.

o. Classify study area: After the intensive test areas have been classified and the statistics have been accepted as sufficient, the entire study area is classified.

p. Data bank: This is a system of programs that is used for the storage and retrieval of the various types of mapped information that have been generated by automatic and manual methods. The system allows the overlaying of selected maps and the performance of logical operations on them to produce an output map that is a composite of the input maps reflecting the constraints specified by the user. See section V for detailed description.

q. Map input: Through use of the comparator capability of the scanner and the coordinate digitizer, mapped data such as soil type, land ownership, and topography can be entered through the CRSR computer facility into the data bank.

r. Generate composite maps: Several output devices are available to produce a wide variety of maps from the human and automatic data entered in the data bank. The color CRT is used to generate easily interpreted color representations of the classes. Computer controlled plotters and precision reproducers are available and are used to generate line drawings that can represent mapped features to any specified scale for overlaying on existing maps. The high resolution CRT can also be used to generate line drawings to predetermined scales.

s. Estimates of areas: Through the use of the data bank and a system of summary routines, estimates of areas in each class and their locations can be produced. Through statistical routines corrections in estimates can be applied to the output. These corrections are obtained from data generated in the intensive test areas earlier in the processing.

t. Spot check classification results: Because of the high degree of accuracy that is desired, spot checks of the results are made outside the intensive test sites. This is necessary because of the variations in feature characteristics with changes in geographic region.

u. Check boundary delineations: When two or more methods or data bases have been used to map the same parameter it may be necessary to check and display the differences that occur between the maps.

2.5.2 Hardware

Our approach to hardware acquisition to date has been motivated by the need to consider resource analysis using aircraft and telemetered data as well as "hard-copy" reproductions from aircraft and spacecraft image acquisition platforms. In the process of preparing for ERTS, Skylab and Aircraft Imagery, the CRSR has developed a computer system which has local preprocessing and display capabilities (Figure 2.17) as well as a data link to high speed, high capacity digital computers at remote locations of the University of California campus. The types of large scale computers which are available for use include: a CDC 6400, a CDC 6600, and a CDC 7600. Standard peripherals such as line printers and X-Y plotters are also available.

The CRSR computer system has the following hardware components:

- Digital computer
- Interactive color display
- High resolution black-and-white graphics CRT
- Digital disc memory
- Digital 9-track tape transports
- Digital cassette recorder
- High speed paper tape reader/punch
- Card reader

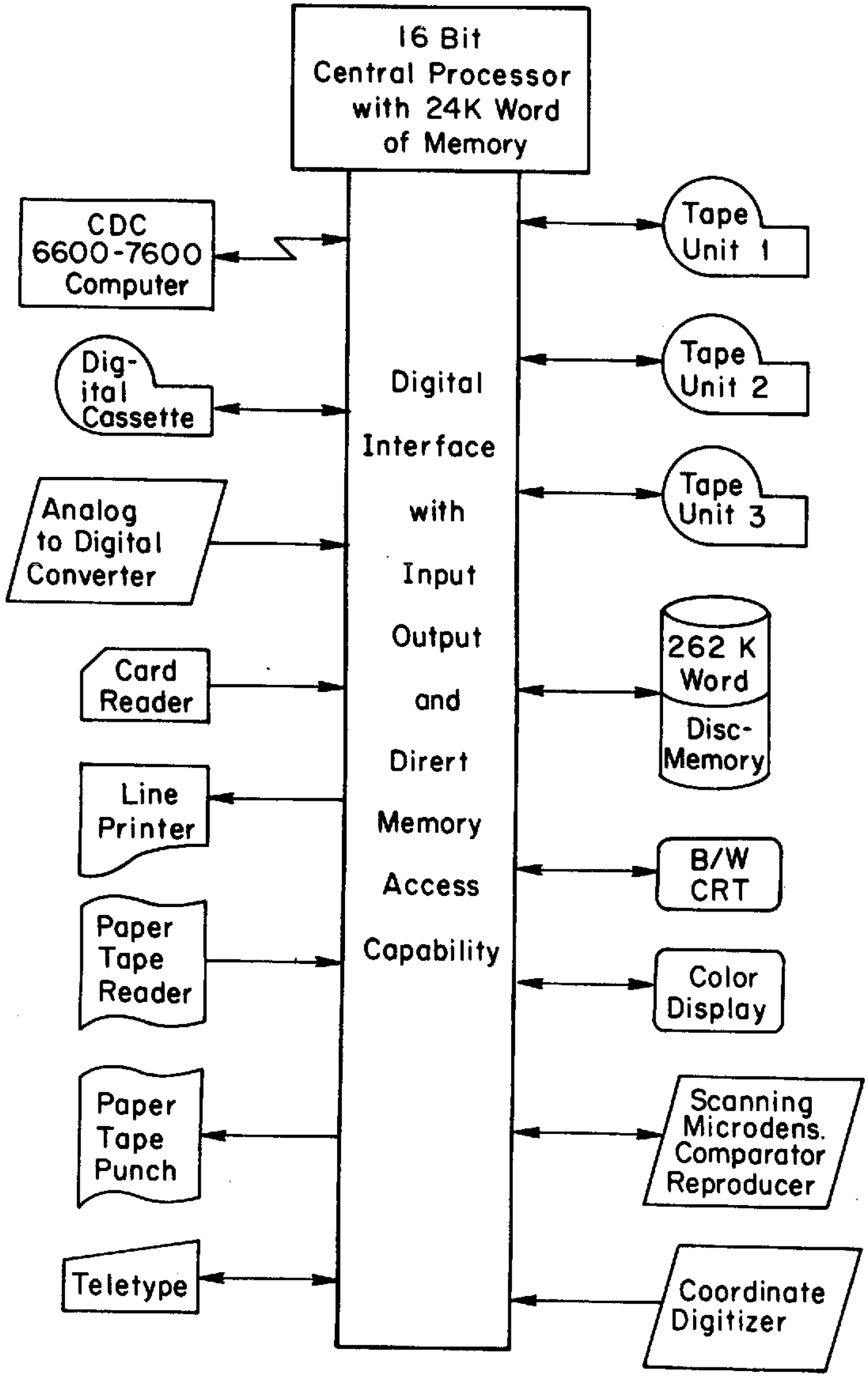


Figure 2.17. The CRSR automatic data processing hardware system.

- Line printer

- Coordinate digitizer

- Custom scanning microdensitometer/comparator/reproducer

- High speed data link to large scale computers

- A/D converter

The components of the system are described in detail below.

a. Small computer process control devices: The heart of the system consists of a small computer (the NOVA by Data General Corporation) which serves as a "process controller" and also as a CPU for limited digital analysis requirements. It is a 16-bit word length, 4-accumulator device with a 24K words of memory. Memory cycle time is 2.6 micro-seconds. It is capable of serving up to sixty-four peripheral devices. It presently services the following components.

b. Interactive color display: This subsystem consists of a 19-inch color monitor that accepts red, green, and blue inputs from three scan conversion memory tubes (SCM). Each SCM is capable of storing a 1024 x 1024 array of picture elements generated by the computer. The display electronics output these images in a 525 TVL format to the monitor. The SCM's further enable registration of the three bands and "zooming" in on points of interest. A light pen is also provided for interactive selection and display of information.

c. High resolution black-and-white graphics CRT: This interactive device consists of a high resolution CRT that receives its input from a hardware vector/character generator controlled by the computer. The graphic and alphanumeric data that are being displayed can be modified through the use of a "joy stick" controlled cursor. The data displayed can also be transferred to hard copy for future reference.

d. Digital disc memory: This 4.19 megabit high speed bulk storage device is used for image manipulation and program storage.

e. 9-track tape transport: Three tape handling units exist on the system for efficient tape reformatting purposes and rapid bulk data manipulation and sorting functions. The units are capable of reading and writing at 800 bpi with 37 ips.

f. Digital cassette recorder: This unit serves as a data storage and program file system. Each cassette has a pre-recorded addressable track with over 7,000 addresses available for random access by the user. Average access time is 15 seconds. Each tape cassette is capable of storing 3 megabits at a packing density of 1,000 bpi.

g. High speed paper tape reader/punch: High speed paper tape I/O rates of 300 characters per second punch are available for program development and intermediate paper tape output requirements.

h. Card reader: An additional flexible form of I/O for analytical work and program development on the System is provided by the card reader which has a capacity of 400 cards per minute.

i. Line printer: This 200 line per minute 132 column printer is the primary output device for local computational work and remote jobs run on the large scale computers.

j. Coordinate digitizer: To facilitate digitizing of mapped information this device was recently added to the system. It accepts up to 14 x 14 inches of mapped data and allows manual digitizing of coordinates in several modes. Resolution is 142 points per inch (.007 inch/pt.).

k. Custom scanning microdensitometer comparator reproducer: This device accepts transparencies -- color or black-and-white -- up to 9 inches square. It is capable of digitizing at an X and Y resolution of 0.005 inch and a "Z" resolution of 4,096 grey levels. It is capable of sampling at a rate of nearly 2,000 points per second under computer control or manual coordinate digitizing. It is also equipped to reproduce black-and-white positive or negative images directly on film at 1000 lines per inch while removing image distortions such as the skew found on ERTS data.

l. Data link: A conventional telephone line data link (interactive and full-duplex) is employed for data transmission to the large scale computers on the Berkeley campus. The live data link operates at 9.6K band.

m. A/D multiplexer converter: This 12 bit, 12 microsecond analog to digital converter has a ten channel analog multiplexer as input. It is used to digitize signals from the light pen, joy stick, scanner, and field FM recorder/reproducer.

2.5.3 Image Handling and Display

A package of several Nova programs permits the preparation of various input tapes for CALSCAN from ERTS MSS 9 track digital tapes, and the display of the CALSCAN results.

a. MSS REFORMATTER: The MSS REFORMATTER rewrites an entire ERTS MSS bulk tape into the CRSR internal format which is compatible with the CALSCAN input format. One such tape covers one quarter of an ERTS frame, that is, a 25 n by 100 n strip.

b. COLOR DISPLAY: The program COLOR DISPLAY is a display and editing program for CRSR internal format ERTS MSS tapes produced by the reformatter. Up to two adjacent quarter-frame tapes may be displayed or edited at a time, and designated portions of those tapes can be rewritten onto another tape called a test tape; it is the test tape that is submitted to CALSCAN. At present, the maximum allowable file size for test tape files is 1024 points by 1024 lines, or about 32 n by 43 n; the minimum is 2 points by 2 lines. Up to three MSS bands from either the test tape or the quarter-frame tapes can be displayed on a color monitor in three colors of 32 grey levels each. The user may designate what portions of a tape to display and the program will magnify that portion so that the picture fills the screen; if a small enough portion is requested individual MSS resolution elements can be seen. The maximum picture size is 1024 points by 1024 lines, and the minimum is 2 points by 2 lines. A particular point or groups of points may be chosen to use for training areas, for the starting point of a new color display, or for the starting point and length of a test tape file, etc. by using a light pen and/or a grid superimposed on the display. If the light pen is used, when it is pressed against the monitor screen, the program will print the coordinates of that point. If the grid is used, the grid spacing and starting point may be designated. COLOR DISPLAY also has an option to print the contents of a designated tape record onto a CRT so that one can read the MSS reflectance readings directly from the tapes.

c. Multi-date tape create and display: The multi-date programs create a multi-date tape from several test tapes that were output from COLOR DISPLAY, and display that tape. To make the multi-date tape, which can be input into CALSCAN, the program superimposes two or more test tape files of one particular area's reflectance readings from different ERTS passes. Then any three bands from the multidate tape can be displayed and training areas can be chosen in a manner similar to COLOR DISPLAY. By running CALSCAN with more than one date's data it is possible to detect and monitor seasonal changes.

d. CALSCAN COLOR DISPLAY: This routine allows the user to display CALSCAN output that has been written on magnetic tape (i.e. classified areas) on the color T.V. monitor. The user specifies what portion of the area he wishes to display and assigns colors to each classification type in the image. The routine provides forty different colors for the user's selection. After displaying, the routine provides the user with a count of each classification type within the displayed area.

e. TEXTURE: In an attempt to quantify the texture of digitized photographs and ERTS data, a program was written that calculates sets of sequency coefficients, using a modified Hadamard transform and sets of means and standard deviations of the input density readings or reflectances. The coefficients, means, and standard deviations are written out onto magnetic tape in a format compatible with CALSCAN and can be

combined in that program with any spectral information. The size of the sequency coefficients is sensitive to the size of the features in a given area, to their spacing, and to the contrast between adjacent features. Thus, the sequency coefficients from a picture of an agricultural area are drastically different from those of an urban area. The means and standard deviations measure differences in density or reflectance so that two areas of differing average density but identical sequency coefficients can be distinguished from one another; for example, the means would show the difference between small dark features on a light background and small light features on a dark background while the sequency coefficients would not.

f. A group of three programs allows creation and manipulation of magnetic tapes containing digitized linear information from maps and images. Some examples of this type of information are natural or political boundaries, topographic elevation lines or field boundaries. This information can be used as additional input to CALSCAN or MAPIT.

DIG-SCAN and DIG-GRAF: These two routines create the magnetic tape and differ only in that they use different devices as the digitizer. Only one type of "structure" can be digitized by these routines, and that structure is a closed loop. That is, any line surrounding an area can be digitized. The digitizing process involves breaking up the irregular or curved portions of the line into a series of short straight line segments and recording the X-Y positions of the end points. Consequently, the digitized information is an approximation of the original line. The degree of accuracy of this approximation is under the user's control. Each digitized loop is written onto the tape in a particular format, but the user can organize this information into files however he likes.

DIG-DISPLAY: This program has two functions. First, it allows the creation of new tapes from selected portions of existing digitized tapes. In this respect, it acts as an "editor" of digitized tapes. Its second function is to graphically display data from an existing digitized tape and compute the areas enclosed by each loop. The display is done alone or in conjunction with the creation of a new tape.

2.5.4 Discriminant Analysis

Three automatic image analysis programs: (1) STRATIFY, (2) CALSCAN*, and (3) RECLASS were implemented to combine the human and computer capabilities and thereby optimize the process of extracting resource information from remote sensing multi-feature imagery.

*CALSCAN is a version of the discriminant analysis program developed at the Laboratory for Applications in Remote Sensing at Purdue.

a. STRATIFY: When ERTS imagery is processed, several factors affecting the cost and accuracy of land use classification become apparent. (1) There are numerous, irregularly shaped areas in the imagery which can be rapidly delineated into classes by the photo interpreter accurately enough to meet user requirements. (2) Some of these areas, because they are of little or no interest to the user, can be disregarded. (3) In localized areas, detailed automatic spectral pattern classification of plant species and plant communities can be done with a high degree of accuracy. (4) Computer classification costs increase rapidly with the number of classes being considered for each picture element. (5) There is a one-to-one relationship between the number of points being classified and the cost of computer classification.

With these factors in mind, a software system has been developed at the CRSR that integrates human and computer capabilities to increase classification accuracy and reduce processing costs.

Human and automatic processing of the ERTS data goes on in parallel as shown in Figure 2.18 to the point where the information generated by both methods is merged and the final product is output in the form of a classified image and summary statistics.

Human processing starts using the appropriate ERTS image of the study area. The interpreter quickly delineates gross differences in land use classes, such as wildland, urban and agriculture. If possible, these classes are further subdivided into meaningful subclasses. In agricultural areas, they can be delineated on the basis of general tone and texture differences (Figure 2.19a) that relate to crop type and field size. In wildland areas, delineations which represent general vegetation systems such as grasslands, brush, trees, and barren areas, can also be made based on tone and texture. The boundaries of the strata are then digitized and recorded on magnetic tape, using either the comparator or coordinate digitizer, and a description of each individual stratum is entered on the tape. The image coordinates of control points are also recorded to be used to relate the image coordinate system to the ERTS tape coordinate system.

At this point in the processing, the tape coordinates of the control points obtained from the reformatted study area, along with scale and skew data, are input into a transform which then converts photo interpreter strata coordinates to tape data coordinates. This transformation is verified and then applied to the digitized coordinates of the strata boundaries. This produces a point-by-point overlay in which each boundary point corresponds to an ERTS picture element. Within these boundaries each point on the ERTS tape is then assigned to the corresponding photo interpreter stratum. The training set for automatic classification is extracted by stratum from the ERTS image, statistics computed and test sets classified to ensure accurate classification within each stratum.

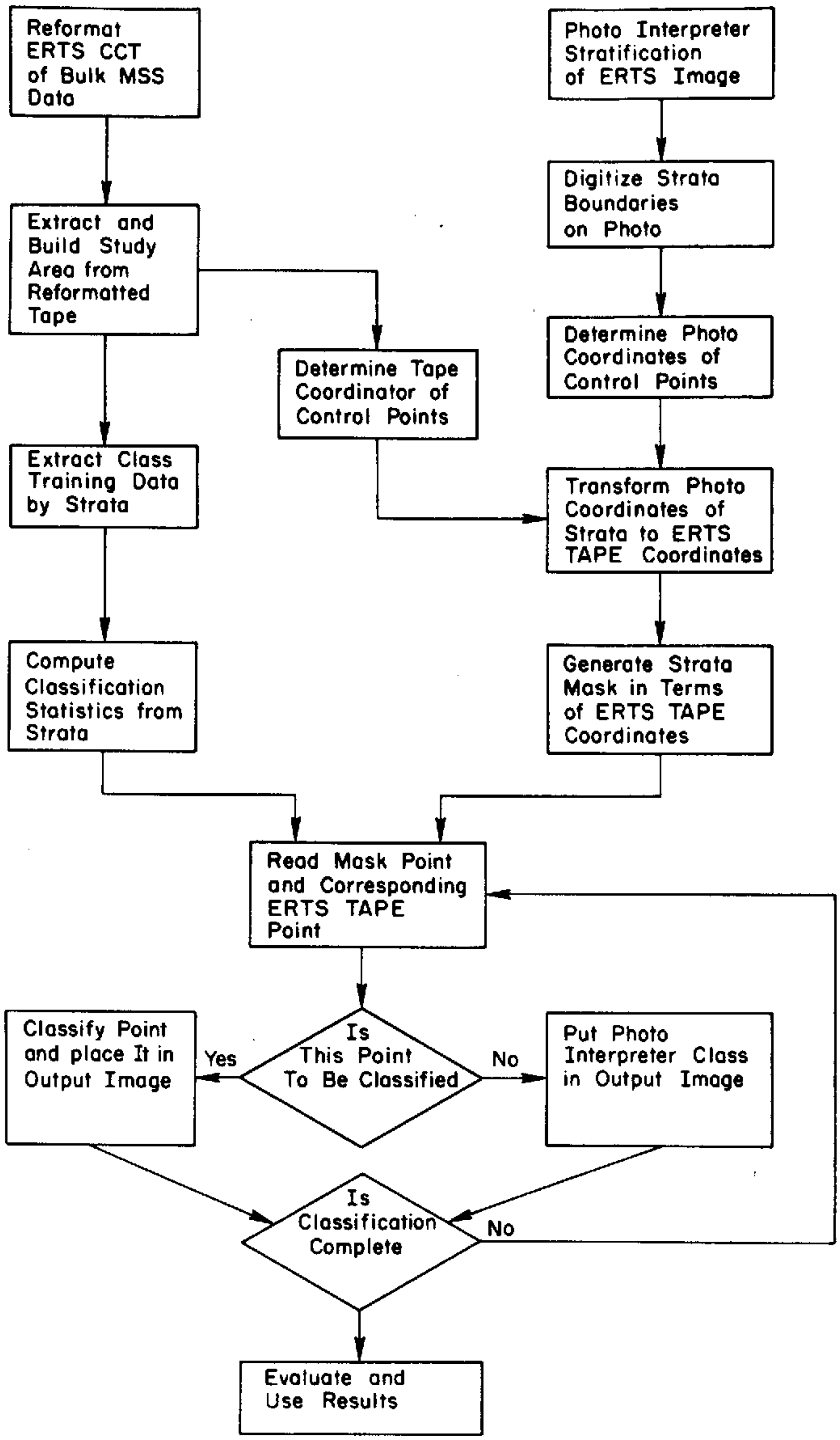


Figure 2.18. This flow chart represents the basic processing of an ERTS image that integrates the human and computer information extraction capabilities to optimize the cost effectiveness of the system.

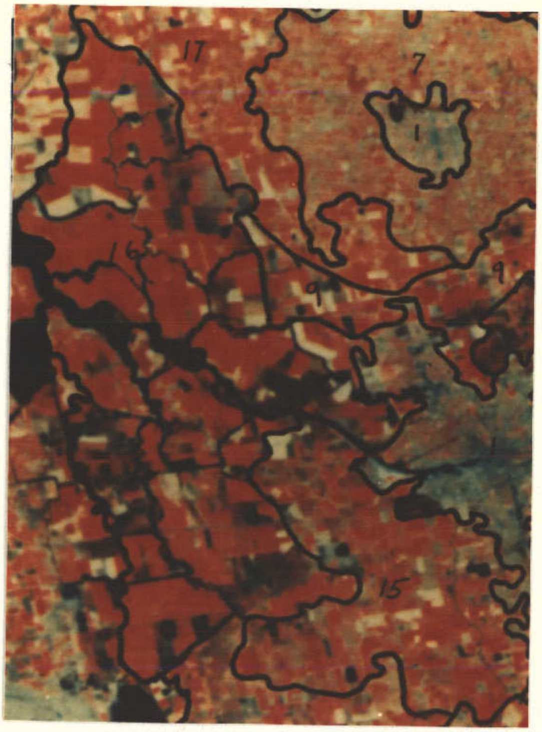


Figure 2.19a. A standard color composite made using ERTS-1 MSS bands 4, 5, and 7 of a portion of the San Joaquin County test site, with the stratification of homogeneous areas as delineated by photo interpreters shown.

Figure 2.19b. The results of the discriminant analysis of the four ERTS-1 MSS bands from July 26, 1972. The computer analysis was restricted to a homogeneous stratum as delineated on the ERTS color composite shown in Figure 2.2.

Green = Asparagus
Yellow = Corn
Red = Sugar beets
Pink = Alfalfa
Pale blue = Tomatoes
Black = Urban
Blue = Water
White = Harvested

The next step is the detailed classification of each of the ERTS picture elements. A picture element and the corresponding stratification point are read. If the stratum is one to be spectrally classified, the classification is done and the results put in the corresponding point of the output image. If not, the photo interpreter stratum is put in the output image. This is continued point-by-point or by some sampling scheme until the processing is completed. The resultant image (Figure 2.19b) is a combination of photo interpretation and automatic classification with a statistical summary of the classification. In addition to the photo interpreter's delineation of strata, existing geological, geographical, or political maps can be used to stratify the ERTS data for classification or used to partition the statistical summary into meaningful reporting areas after classification.

Computer costs are reduced significantly by reducing the number of classes to be considered during automatic point-by-point classification. If, for example, forty classes exist over the entire study area but through stratification only eight classes are considered for each point using ten strata, a four to one reduction in computer costs would be realized. A second source of saving is the elimination of areas from automatic classification by interpreter delineation when the human can adequately specify the land use or that the area is not of interest to the resource manager. This saving is nearly one to one for each point eliminated, but the saving is reduced by the computational overhead needed to determine the point-by-point strata assignments.

The classification accuracy is increased significantly by separating, through stratification, classes that have spectral signatures so similar that they cannot be separated by the discriminant analysis routine.

b. CALSCAN: CALSCAN is divided into four logically independent units -- STAT, SELECT, CLASSIFY and DISPLAY. They are related sequentially, in the order listed. STAT produces data used by SELECT and CLASSIFY; SELECT produces output which facilitates the efficient use of CLASSIFY; CLASSIFY produces data used by DISPLAY.

STAT performs statistical analyses on specified training fields and prints the results in various forms, as directed by the user. These data indicate which classes are separable on the basis of the training data given and which features offer the best separation.

SELECT analyzes the results from STAT to determine which combination of m features out of the n available (m less than n) offers the best separability for all classes and/or for specified class combinations on the basis of the specified training sets.

CLASSIFY uses the training results from STAT to classify image data.

DISPLAY processes the map produced by CLASSIFY to produce statistical summaries of the program's performance. The map may be transformed in various ways according to user options.

There are four types of input to CALSCAN. These are a control card deck, which directs the operation of the program; a multi-feature data tape for some area of terrain to be analyzed and classified; a stratification data tape for the same area to simplify the classification process by providing a human pre-classification; and data sets produced by one part of the program and saved in some form for further use by some other part.

The program produces four types of output, two for the user, and two for itself. For the user, all four subprograms produce printed output; CLASSIFY and DISPLAY can also produce copies of the classified map on magnetic tape in a digital format for display on the CRSR color monitor; STAT saves its results on a disk file set which can be copied on to the IBM 2321 data cell or a magnetic tape, from which it can be retrieved for later use by SELECT or CLASSIFY. CLASSIFY also saves a digital copy of its map output (the classification) on a disk or tape for subsequent use by DISPLAY.

c. RECLASS: The automatic classification of wildland areas using spectral data is made difficult by the non-homogeneous nature of plant communities. Two problems are that the species of interest does not always cover the majority of the ground area in the site and the discrete scanned points do not always fall completely within a specific species type. Therefore, the resulting density levels are an integration of spectral information from more than one species. When these data are used in the classifier the results are usually not meaningful. The probability that a point represents a single species of interest is determined by many factors which include the effective area of integration of the spot on the ground, the spacing between spots, the surface area covered by homogeneous blocks of the species, and the total percent cover of the species. To solve these problems, an algorithm (RECLASS) has been developed which increases the accuracy of type delineation by weighting those that do not have a high percentage ground cover to create a representation which corresponds to the requirements of the resource manager.

The "weight-by-neighbors" clustering algorithm looks not only at each individual point, but also takes into consideration the eight surrounding points comprising a 3 x 3 matrix. For example, if the following is the 3 x 3 matrix for the point of reference, 0, then point 0 (in the center position) would be reclassed as "X" because a plurality of the points are classed as "X". In the event of a tie, the decision is arbitrarily given to the first of the tied classes under consideration, unless one of the tied points was the center point, in which case the decision would be given to the center point.

```
( X X X )
(       )
( X 0 X )
(       )
( X X X )
```

When for mapping purposes it is desirable to have the areas where a species occurs above some minimum level mapped as one type, an unequal weighting is applied to each point in the class.

2.5.5 General Statistics

2.5.5.1 Multistage Inventory Programs

While these programs were developed for use in the timber volume studies described in Chapter 4 of this report, their use can be extended to any of a large number of resource inventory applications.

Plot Selection by Random List Sampling (PLTCHOZ)

From data relative to average stand height and percent crown closure the program calculates the timber volume of a plot, using existing aerial photo volume tables. These volumes are cumulatively summed over a set of plots and a designated number of plots are randomly selected on the basis of their cumulative volumes. This list sampling selection method favors plots with high volumes.

Photo Scale-Radius Calculations (SCALRAD)

For the plots selected from PLTCHOZ, this program calculates the photo distance to ground distance scale factor and an appropriate plot radius on the photo given the camera's focal length, the altitude of the aircraft taking the picture, ground elevation, the negative to print blowup factor, and an appropriate ground distance. The scale factor is used in later programs and the plot radius delineates the area on the photo that will be inventoried by field crews.

Tree Selection by Random List Samplings (TRECHOZ)

This program selects which trees within the area delineated with SCALRAD will be measured by dendrometer. From crown diameter measurements from the photo and the scale factor from SCALRAD the program calculates the crown diameter cubed, a rough approximation of volume. In the same manner as PLTCHOZ, several trees are randomly selected on the basis of their cumulative sum of crown diameter cubed.

Weighted Cell Analysis (BREAKUP)

This routine works on output tapes from CALSCAN (i.e. classified areas). The routine breaks the area up into small cells and based on a weight assignment for each classification type, computes a "weighted sum" for each cell. Depending upon the assignment of weights, this weighted sum can represent estimated dollar values, estimated timber yield, percentage of a particular classification type, or other values. The cell size and weights are set by the user.

In addition to the weighted sum for each cell, the weighted sum for the whole area and the mean and standard deviation between the cells are computed.

2.5.5.2 Special Purpose Statistics Programs

Chi Square (CHISQ)

To test whether two characteristics are independent of each other or not, this program computes chi-square values from a two dimensional matrix of observed frequency values. It computes the expected frequency value and chi-square for each observed value, the chi-squares for each row and each column, and the chi-square and degree of freedom for the entire matrix. One can then look up the probability of dependence in a chi-square table.

Two Way Analysis of Variance (TWAV)

To determine whether the means of two populations are significantly different from each other, this program computes the F ratios and degrees of freedom as described in sec. 10-4 of Dixon and Massey's Introduction to Statistical Analysis, given the two sets of data measurements. One can then look up the probability of similarity between two means in an F ratio table.

Double Sampling (DBLSMPL)

This program calculates a linear regression equation to compute unknown Y's for a large population of X's. The equation's constants are derived from the X values of the large population, X values from a small population, and Y values from the same small population as described in Fresse's Elementary Forest Sampling, pp. 43-46. Double sampling of X is a useful way to calculate Y when the X population's mean or total is unknown.

One-way Analysis of Variance (OWAV)

This program gives the same results as TWAV above, but is one-way rather than two-way.

Chapter 3

USE OF ERTS-1 DATA AS AN AID IN SOLVING WATER RESOURCE MANAGEMENT PROBLEMS IN CALIFORNIA (UN643)

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3.1 INTRODUCTION

Water requirements for both urban (municipal and industrial) and agricultural uses have led to comprehensive programs of water development. Planning and development of large water systems together with their operation is perhaps summarized in terms of where the water occurs, when, how much and in what form, and logically where, how much and when water is needed by users. Remote sensing offers a potential new dimension to this field of endeavor. A strong effort needs to be directed toward concepts of quantification of data derived from remote sensing, especially for water resource and hydrologic use. Remote sensors of the imaging type permit qualitative comparison or evaluation quite readily and thus are useful for monitoring and for comparative analysis. Many investigators are seeking to provide insight and methodology for the useful measurement of water-related phenomena. While these results are not yet fully developed nor in operational use, this objective for the interpretation of ERTS-1 imagery and data extraction is of highest priority.

During the period from September 1972 through June 1973, imagery acquired from the ERTS-1 satellite has been provided to this project covering that section of California designated as the Sacramento-San Joaquin River Delta Test Site.

The opportunity to assess the potential of remotely sensed data from a satellite platform for application to a broad array of operational tasks has been pursued during the study.

This report summarizes the applications of ERTS-1 and supplementary imagery sources which we thus far have found applicable to water resources planning, operations and management.

3.2 SUMMARY OF WORK DONE

In our earlier assessments, work was undertaken to define the parameters involved in the hydrologic processes and subsystems of the water cycle. Parameters of the subsystems were defined on the basis of the operational tasks performed currently by water resource agencies. These components were reduced to the fundamental hydrologic process or function. This procedure provided a listing of parameters designed to be responsive to the needs of users of data. The parameters were further defined in terms of the type of measurement required, and the magnitude, resolution and frequency of data acquisition needed for several levels of intensity in operational tasks.

The continuing phases of this research are currently centered in developing alternative parameters or analytical methods to adapt remotely sensed information to the user tasks. ERTS-1 imagery was studied intensively for these purposes, exploiting the fact that the ERTS-1 satellite provides a synoptic level coverage of study areas in California on a repetitive cycle of eighteen days, weather permitting. The test site

provides a wide variety of conditions and examples of targets of hydrologic and water resource interest. The repetitive coverage throughout the year permits study of seasonal changes, a particularly important factor in the area where precipitation is largely a winter season occurence and extended dry periods persist for the balance of the year.

Several specific areas in the Sacramento-San Joaquin Delta Test Site were used in evaluating ERTS-1 imagery for application to typical water resource management problems. Although results to date are only for the partial year of analysis, completion of the annual cycle is expected to yield additional bases for interpretation. Longer term operational analysis of ERTS-1 data will produce a wider range of experience for hydrologic interpretation and applications, embracing greater extremes of natural processes and increasing the data base for quantification of sensor response with ground truth studies.

Three specific characteristics of this satellite are valuable for the test site conditions:

1. Repetitive coverage over seasonal and annual cycles.

2. The imagery format is readily adaptable to a variety of enhancement procedures to increase the derivative results.

3. Resolution characteristics and spectral band coverage provide great opportunity for detailed examination of other target subjects and other interpretive techniques.

The test area includes: mountain watersheds; foothill and valley basins; snow pack regions; large river systems; flood-water control facilities; deltaic areas; agricultural lands, both irrigated and non-irrigated; dams and reservoirs operated for multiple purposes including water supply, flood control and recreation; urban areas; lakes, both eutrophic and oligotrophic; and further provides examples of most of the important water conditions of concern to hydrologists.

All of the aforementioned water-related components were contained in the images, and may be directly compared for the extremes of seasonal effect.

Specific hydrologic elements that were discerned include:

-- watershed physiography (drainage network) features
-- water body locations (natural and man-made)
-- canals
-- large and small river systems
-- deltaic areas
-- flood control works
-- flooded delta islands
-- snow on higher mountain slopes
-- wet lands (seasonal)

-- irrigated agriculture
-- dry land agriculture
-- many additional water-related features

Seasonal effects in terms of both atmospheric attenuation and sun angle tend to reduce the image quality in the winter at this latitude.

Analysis of the imagery was made both on the four Multispectral Scanner bands provided and also on color composites prepared by the diazo process and then enlarged photographically. Detailed discussions of most of the subjects were contained in progress reports issued periodically during the study year.

The reader is referred to the publications issued by NASA-GSFC, entitled "Proceedings of the Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1", Volumes I, II and III, March 5-9, 1973, edited by Stanley C. Freden and Enrico P. Mercanti, Goddard Space Flight Center, Greenbelt, Maryland.

In particular, Volume II contains works presented in the special applications session, wherein detailed discussion and illustrations prepared by this project coinvestigator were contained in the presentation entitled "Application of ERTS-1 Data to Aid in Solving Water Resources Management Problems in the State of California" by Robert H. Burgy.

That report summarized many water resources application potentials of ERTS-1 derived information with great emphasis on the need for development of techniques for measurement of quantities.

Summarizing the kinds of water resource-oriented uses of ERTS-1 effective use of the imagery has been demonstrated for defining a variety of subjects and features in this test area including:

-- the presence and location of water bodies
-- the boundaries of watersheds
-- the quantity of water
-- the relative quality of water
-- the sources of water quality constituents

In the course of our studies we also have been able to determine, for most of these subjects and features, the optimum times of the year for ERTS-1 data acquisition.

Our results indicate the great value of the synoptic coverage provided by ERTS-1.

Several significant points derived from the studies may be listed:

1. The synoptic coverage of the earth provided by ERTS-1 is ideal for regional water resources planning and operations.

2. ERTS-1 imagery lends itself directly to water resource and hydrologic interpretations.

3. The spectral ranges (bands) provided by ERTS-1 are directly useful for both qualitative and quantitative evaluation of water-related parameters.

4. The sequential coverage of ERTS-1 provides the capability to assess and quantify seasonal changes, specific responses and changes on watersheds and in both large and relatively small water system components.

5. The potential applications and the data quantification capabilities of ERTS-1 image analysis are extremely broad-scoped. Enhancement techniques becoming available will make the imagery adaptable for many additional uses.

6. In combination with intermediate elevation platforms, including the high flights by U-2 aircraft, ERTS-1 should be continued in operation to provide a valuable source of data for hydrologic and water resource applications.

3.3 A LOOK TO THE FUTURE

Implementation of programs for the application of satellite-based remote sensing is well underway at both state and local levels as well as by national agencies. Training of key personnel within water resources agencies is an essential factor and is being accomplished through work sessions, university course offerings and by on-the-job assignments.

Based on research performed to date it is our prediction that ERTS-acquired data will be rapidly integrated into operational status to provide a cost-effective tool for solutions in water resources management.

Chapter 4

ERTS-1 DATA AS AN AID TO RESOURCE MANAGEMENT IN NORTHERN CALIFORNIA (UN257)

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Mike Gialdini, Sipi Jaakkola, Paul F. Krumpe
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Center for Remote Sensing Research, Berkeley Campus

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4.1 INTRODUCTION

The Center for Remote Sensing Research (CRSR) at the University of California, Berkeley Campus, has completed more than one year of work designed to determine the usefulness of ERTS-1 imagery for inventorying and monitoring wildland resources in northern California. The work was conducted in two large wildland areas, namely, the Feather River watershed and the Northern Coastal Zone (see Figure 4.1).

The 2.25 million-acre Feather River watershed area in northern California is the keystone watershed for the California Water Project, one of the most extensive and ambitious water resource developments ever attempted. Consequently, accurate and timely information on the quantity, quality and distribution of timber, forage, water and recreational resources is of immediate importance to each public agency and private group managing this vast, but inaccessible, wildland area.

Likewise, the 6.63 million acre Northern Coastal Zone (consisting of the counties of Marin, Sonoma, Mendicino, Humbolt and Del Norte) is relatively rural, with an economy based on agriculture, timber, commercial fishing and tourism. However, it is expected that intensive resource use resulting from increasing population will soon become a serious problem unless wise land use planning is undertaken. Thus, this coastal region is particularly well suited to investigations of the ways in which ERTS-1 imagery and other supporting data may be used in conducting land use evaluations.

4.1.1 Approach

The Center for Remote Sensing Research has applied a systems concept and team approach in performing the work reported in this chapter. The Center is organized into five functional units and these units apply themselves to the most important problems which must be solved if ERTS-1 and supporting data is to be employed successfully for wildland resource inventory purposes. The five problem areas investigated by the units under this team approach are as follows:

1. Determination of the feasibility of providing the resource manager with operationally useful information through the use of remote sensing techniques;

2. Definition of the spectral characteristics of earth resources and the optimum procedures for calibrating multispectral remote sensing data acquired of those resources;

3. Determination of the extent to which humans can extract useful earth resource information through a study of remote sensing imagery either in its original form or when enhanced by various means;

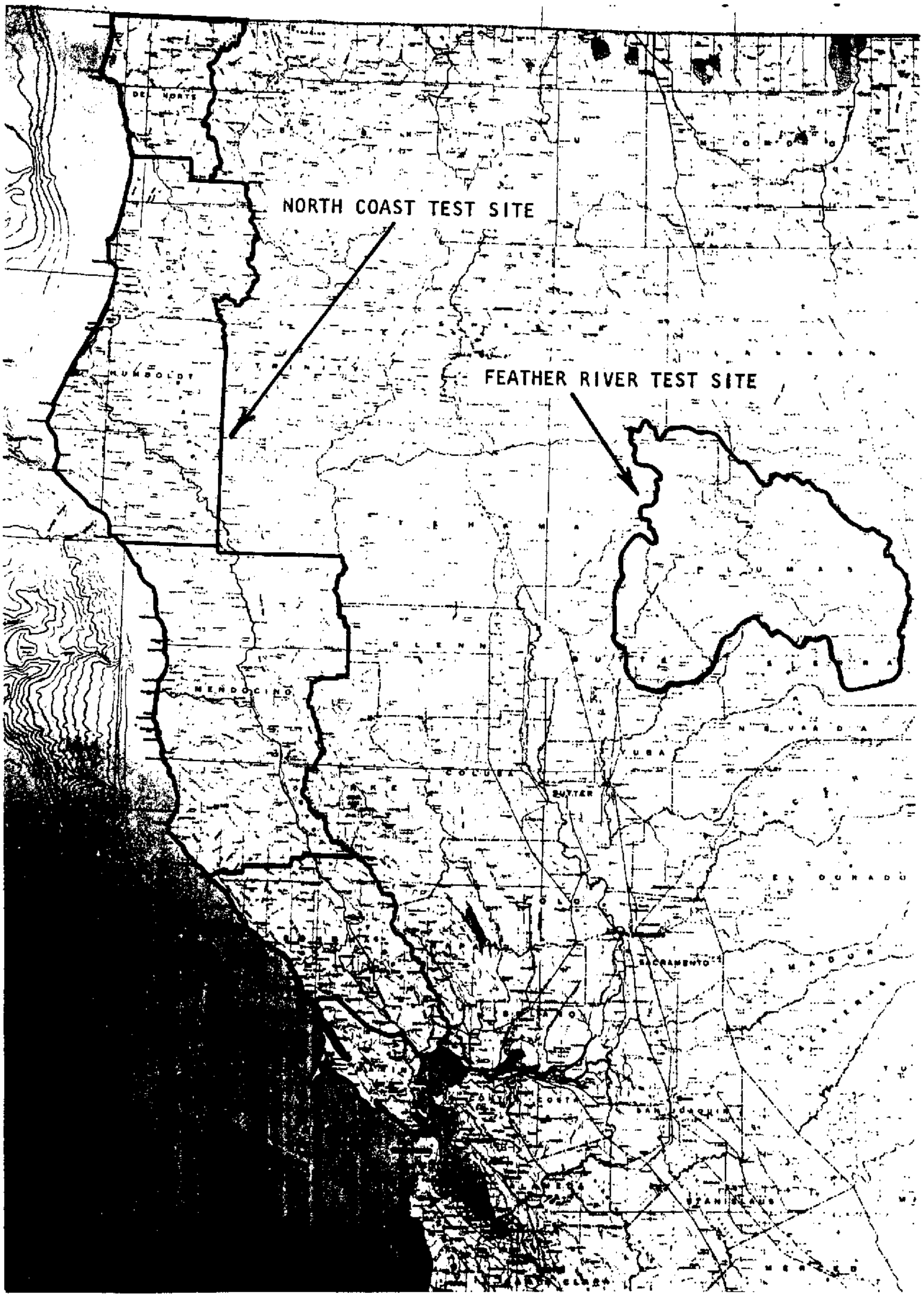


Figure 4.1. The Feather River watershed (2.25 million acres) and the North Coastal Zone (6.63 million acres) test sites in northern California.

4. Determination of the extent to which automatic data handling and processing equipment can extract useful earth resources information from remote sensing data; and

5. Effective dissemination of remote sensing results through the offering of various kinds of training programs in which the interaction between users and scientists can be emphasized.

The units at the Center which are engaged in these five problems are, respectively: (a) the Operational Feasibility Unit, (b) the Spectral Characteristics Unit, (c) the Image Interpretation and Enhancement Unit, (d) the Automatic Image Classification and Data Processing Unit, and (e) the Training Unit.

The work performed within the Feather River watershed and North Coastal Zone test sites stressed both the applications of ERTS-1 imagery and the benefits derived from these applications. Thus, emphasis in the results reported below has been placed on documenting levels of accuracy, degree of timeliness, and costs associated with utilizing ERTS-1 and supporting data for inventorying wildland resources.

4.1.2 Summary of Significant Results

Significant conclusions resulting from work done within the Feather River watershed region are summarized below:

1. Numerous manual image interpretation tests were performed which were designed to evaluate various components of the ERTS-1 system (see pages 4-16 to 4-36). Detection of wildland resource features and conditions was done acceptably well on single-band, single-date ERTS-1 imagery, but identification of the resources was more difficult. On a single-date color composite transparency, however, a skilled interpreter could detect and identify sixteen specific resource types 67 percent of the time and nine broad types 73 percent of the time. In addition, tests showed that a three-band electronic enhancement and a two-band color composite were best among the image types tested for classifying commercial conifer forest.

2. A quasi-operational study was performed and demonstrated that ERTS-1 imagery is ideal for making vegetation/terrain type maps using manual interpretation techniques (see pages 4-36 to 4-47). In this demonstration project a vegetation/terrain map was prepared from ERTS-1 imagery for the entire 2.25 million acre Feather River watershed and required only 11.5 hours of interpretation time. The ERTS-1 map had an accuracy level of 81 percent. A similar map made using conventional methods -- compiled from both current and outdated data -- had an accuracy level of 68 percent. Furthermore, the ERTS-1 map was prepared at approximately one-third the cost of the conventional map.

3. A quasi-operational study demonstrated that a timber inventory based on manual and automated analysis of ERTS-1 and supporting aircraft data could be made using multistage sampling (see pages 4-47 to 4-68).

The inventory using ERTS-1 imagery for the first stage proved to be a timely, cost-effective alternative to conventional timber inventory techniques. The volume on the Quincy Ranger District (215,000 acres) of the Plumas National Forest was estimated to be 2.44 billion board feet with a sampling error of 8.2 percent. Costs per acre for the inventory procedure at 1.1 cent/acre compared favorably with the costs of a conventional inventory at 25 cents/acre. A point-by-point comparison of CALSCAN-classified ERTS data with human-interpreted low altitude photo plots indicated no significant differences in the overall classification accuracies.

Significant conclusions resulting from work done within the North Coastal Zone region are summarized below:

1. One of the greatest applications for analysis of ERTS-1 imagery is in the detection of changes in the resouce base over time (see pages 4-106 to 4-109). For example, when using manual interpretation technqiues, harvesting activities in the timbered regions of northern California could be monitored with ERTS-1 imagery. Also, a determination of the location and an estimation of the size of the harvested area could be made. Other resource changes which can be monitored include: sediment plume size and direction, greening and drying of annual herbaceous vegetation, location and amount of irrigated crops, stage of development of marsh vegetation, and changes in the size of large ponds and lakes. For most of the changes that can be detected or monitored, supporting information from either aerial photographs or ground sampling is required in order to establish the significance of the change.

2. The primary usefulness of vegetation/terrain map information derived from the ERTS-1 imagery in the North Coast is in the display of land use types throughout large regions (see pages 4-80 to 4-95). The ERTS-1 imagery provides a regional perspective of resource types and management units and allows the resource types to be evaluated in terms of their relationship to each other and related to the different types of land management practices. The ERTS imagery can be rectified and enlarged to a workable map scale of 1:250,000 or 1:125,000, thus providing a map base for resource types upon which other sources of map information can be superimposed.

4.2 FEATHER RIVER WATERSHED

4.2.1 Introduction

4.2.1.1 Background

The Feather River watershed possesses a number of characteristics which enhance its value as a test site for evaluating the utility of ERTS-1 and supporting aircraft data.

The California State Water Project is one of the most extensive and ambitious water resource developments ever attempted. The primary source of water for this vast project is the Feather River headwaters region, which drains into Lake Oroville, the keystone of the project in terms of flood control and regulation of downstream water delivery. Thus, the Feather River is an important component of an actual resource development operation. As such, conclusions which are reached regarding the utility of ERTS-1 and supporting aircraft data can be evaluated not only on a purely theoretical basis, but also on decisions that have been made, and in comparison to conventional techniques which have been and are being used to gather needed data.

Most of the actual watershed lands of the Feather River region are administered by the U.S. Forest Service, which is charged with the responsibility of multiple-use management of the resources of the area. Although water storage and power-generation facilities have been highly developed, in many cases the management of the actual watershed lands themselves (to provide an optimum mix of resources including wood, livestock forage, recreational opportunities, fish, wildlife and water) is not currently highly advanced. This is due primarily to an incomplete understanding of the complex man-resource interaction, and a lack of basic data regarding the physical parameters of the vast, wild, and poorly accessible areas involved. Thus, an opportunity exists not only to compare satellite remote sensing techniques against conventional methods of data acquisition, but in many cases to evaluate the potential for providing information that is currently unavailable in the form, or with the degree of accuracy, necessary to permit the development of a highly sophisticated broad-scale resource management system.

4.2.1.2 User Requirements

A primary effort has been made during this project to determine the feasibility of providing resource managers operating within the Feather River watershed with operationally useful information through the use of ERTS-1 and supporting aircraft data. As a first step, therefore, records were compiled of resource management agencies active within the region. Among those federal, state and

private agencies or groups identified were the U.S. Forest Service, U.S. Geological Survey, Bureau of Land Management, Bureau of Outdoor Recreation, California Division of Forestry, California Department of Water Resources, California Soil Conservation Service, California Department of Parks and Recreation, California Division of Highways, California Cooperative Snow Survey, California Comprehensive Framework Study, Plumas County Planning Commission, Lassen County Planning Commission, Plumas County Farm Advisory Office, Plumas County Land Conservation Advisory Board, Pacific Gas and Electric Company and Feather River Lumber Company.

Within many of the agencies and groups listed above, contacts were made with land managers and resource specialists who were keenly interested in the results of this ERTS-1 experiment. Thus, through direct interaction with user agencies, resource management problems and information requirements were well defined at the outset of the experiment, and were refined and updated throughout the duration of the project (see Table 4.1). A specific result from the interaction between members of the CRSR and user groups was that detailed information was obtained about operational resource inventory projects which are currently in progress or have been performed in the recent past within the Feather River watershed.

To further facilitate the gathering of user requirement information, the CRSR held a brief 3-day workshop on the Berkeley campus in March, 1973. Practicing wildland managers representing federal, state and private interests were invited to attend the workshop, and twenty-five persons ultimately participated.

The workshop provided a two-fold opportunity: (1) it enabled the resources specialists to become familiar with preliminary project results describing the utility of ERTS-1 data and high altitude aerial photography, and (2) it permitted the CRSR staff, through discussion with the attendees, to thoroughly define and evaluate a multitude of practical wildland resource management problems. The workshop was presented in three parts -- one day in the lecture room on the fundamentals of remote sensing data acquisition and data analysis; one day in the field with ERTS-1 and high-flight images in hand; and one day in the laboratory on solving practical problems with the aid of remote sensing data.

4.2.1.3 Study Objectives

Three basic objectives were established for the work done within the Feather River watershed. These objectives were (1) to acquire supporting ground data of the necessary kind, amount, distribution and frequency for making reliable evaluations of the ERTS-1 imagery, (2) to test various components of the ERTS-1 system for information content relative to defined user requirements, and (3) to test the

TABLE 4.1. USER AGENCY INTERACTION (FEATHER RIVER WATERSHED)

USER GROUP AGENCY	PERSONNEL CONTACTS	REMOTE SENSING APPLICATION/ INFORMATIONAL REQUIREMENTS
U.S. DEPARTMENT OF AGRICULTURE Forest Service	Mr. Jim McLaughlin (Plumas N. F.) Mr. Paul Limebeck " Mr. John Lowe (Regional Office) Mr. Jack Carter " Mr. Wilber Charter " Mr. Terry Gossard " Mr. Wayne Iverson " Mr. Noel Larson " Mr. Warren Walters "	Land use mapping, timber inventories and timber management, fire planning and management, landscape architecture and recreation planning, soils and watershed management, transportation analysis, multiple use planning and coordination
U.S. DEPARTMENT OF INTERIOR Bureau of Land Management	Mr. Dean Bibles (Susanville District) Mr. Roger Zortman " Mr. Grover Torbert (Washington, D. C.)	Land use mapping, soils mapping, range inventories, timber inventories, multiple-use land management, change detection
CALIFORNIA REGION FRAMEWORK STUDY COMMISSION FOR SOUTHWEST INTERAGENCY COMMITTEE Water Resources Council	Mr. Jim Cook (USFS) Mr. Lyle Klubben (USFS) Mr. William Frank	Regional vegetation/terrain mapping, land use practices and change detection, landslide and stream sedimentation detection
CALIFORNIA DEPARTMENT OF CONSERVATION Division of Forestry	Mr. Tob Arvola Mr. Clint Phillips Mr. Robert Weaver	Land use mapping, vegetation-soils inventory, fire damage appraisal, rangeland control burning
CALIFORNIA DEPARTMENT OF WATER RESOURCES	Mr. Barry Brown	Land use mapping, vegetation-soils inventory, water quality analysis
CALIFORNIA COOPERATIVE SNOW SURVEYS	Mr. Gene Brown	Snow pack detection and mapping, hydrologic output prediction
CALIFORNIA DEPARTMENT OF PARKS AND RECREATION	Mr. George Rackelman Mr. Sandy Rabinowitch Mr. John Haynes Mr. Ed Pope	Land use mapping, site location and planning, determination of recreation land potential, change detection
TAHOE REGIONAL PLANNING AGENCY	Mr. Jim Bruner	Land use mapping, environmental change detection, sediment pollution analysis

TABLE 4.1. (Continued)

USER GROUP AGENCY	PERSONNEL CONTACTS	REMOTE SENSING APPLICATION/ INFORMATIONAL REQUIREMENTS
PLUMAS COUNTY PLANNING COMMISSION	Mr. Darrell Payne	Land use mapping, vegetation analysis, change detection
PLUMAS COUNTY FARM ADVISORY OFFICE	Mr. Art Scarlett	Land use analysis, educational activities
PLUMAS COUNTY LAND CONSERVATION ADVISORY BOARD	Mr. Sandy Pricer	Land use analysis and planning

practical applications of ERTS-1 imagery and supporting data for meeting specific user requirements.

All work performed within the Feather River watershed was focused on three user information requirements: (1) regional vegetation/terrain mapping, (2) specific vegetation/terrain type identification, leading to the production of maps showing distribution and location, and (3) timber volume estimation. These three requirements are of primary importance to a majority of the land managers and resource specialists active within the Feather River watershed -- as noted in Table 4.1. Consequently, for each of the studies designed to test various components of the ERTS-1 system, the work was done in the context of an identifiable and justifiable user requirement. Given this prerequisite, evaluations were made of (1) single-date, single-band black-and-white prints, (2) single-date, multi-band color composite prints, (3) single-date, multi-band color composite transparencies, (4) single-date, multi-band color composite enhancements, and (5) variable-date, multi-band color composite enhancements.

Likewise, two case studies were performed which were designed to determine the practical use to which ERTS-1 and supporting data might be put for meeting a specific user requirement. The first case study demonstrates, in terms of accuracy level, timing and associated costs, how ERTS-1 imagery can be used to make regional vegetation/terrain maps, using manual interpretation techniques. The second case study demonstrates, in terms of accuracy level, timing and associated costs, the utility of ERTS-1 imagery for making a timber inventory using interactive manual-machine analysis techniques and multistage probability sampling.

4.2.2 Acquisition of Supporting Ground Data

4.2.2.1 Field Data Collection

Since the inception of the NASA Earth Resource Survey Program in 1964, the 200 square mile Bucks Lake-Meadow Valley area, which is located in the center of the much larger Feather River watershed, has been a primary Agriculture/Forestry test site (NASA Test Site #20). Thus, more than eight years of intensive ground data collection and remote sensing research has been conducted within the area, and the published results of this work have greatly supported our present ERTS-1 project. Moreover, because of the fact that the University of California, School of Forestry summer field camp was established in Meadow Valley in 1918 and has been actively used for teaching and research purposes ever since, vast amounts of field data collected by staff and students over the last 50 years have been readily available for use of the present project.

It was necessary, however, to augment existing sources of ground data in the Bucks Lake-Meadow Valley area with additional data representative of features and conditions found throughout the entire 2.25 million acre Feather River watershed. The initial approach to gathering these data concentrated on acquiring, compiling, and verifying ground data. This was done by contact sampling of the landscape, by acquiring 35 mm photos from low flying aircraft, and by compiling available resource map data. About four man-months of contact sampling of 150 ground plots within the 2.25 million acre region, resulted in the collection of several important bits of resource data including: (1) photo-map location, (2) aspect of the slope, (3) slope class (percent), (4) leading canopy dominants, (5) understory vegetation, (6) percent vegetation cover, (7) crown closure and (8) stand height. In addition to these observations, current data from 155 ground plots established by the Integrated Forest Survey and Timber Management Inventory were obtained from the regional office of the U.S. Forest Service.

Many other sources of field data were exploited which led to the compilation of the following Feather River watershed maps: (1) lithologic geology, (2) mean annual precipitation, (3) soil series complexes, (4) elevational zones, (5) drainage network (Strahler Stream Order System) and (6) vegetal cover types. The vegetal cover type map, prepared in 1970 by the Comprehensive Framework Study Committee, California Region, is a portion of a larger map of the Sacramento Basin Subregion, and represents pre-ERTS "state-of-the-art" regional mapping prepared from referenced materials dating from 30 years ago to more recently.

4.2.2.2 High Altitude Aircraft Photo Analysis

The most important source of supporting data during this study was vertical aerial photography obtained from NASA high-performance aircraft. Ground data compiled from the 305 field plots, combined with other observations, provided the necessary baseline information for interpreting and mapping the entire Feather River watershed utilizing high altitude, false-color infrared photography. Approximately thirty wildland resource types among seven landscape categories were identified and mapped. Within delineated areas, percent composition was indicated. The classification scheme used is presented in Table 4.2. Major landscape categories include (1) conifer forests, (2) hardwood forests, (3) chaparral, (4) grassland-meadow marshland complex, (5) agricultural and rangeland resources, (6) other landscape features and (7) hydrologic resources. Detailed descriptions of the important vegetation types are presented in Table 4.3. While the map was being produced, these categories were identified, delineated and classified by percentage composition where image characteristics such as color, tone and texture appeared uniform. These areas were delineated and identified on acetate overlays on each of 60 individual

TABLE 4.2. CLASSIFICATION SCHEME OF VEGETATION/TERRAIN RESOURCES OF THE REATHER RIVER WATERSHED REGION.

FOREST RESOURCES

Coniferous Forests

A. Fir Forest
B. Westside Intermediate Mountain Conifer
BB. Eastside Intermediate Mountain Mixed Conifer
C. Eastside Intermediate Pine-Scrub Forest
D. Eastside Northern Juniper Woodland
E. Eastside Timberland-Chaparral Complex

Hardwood Forests

F. Intermediate Mountain Xeric Hardwoods
G. Westside Foothill Pine-Oak Woodland
GG. Westside Foothill Oak Woodland-Grass
GC. Westside Foothill Oak Woodland-Chaparral
GGC. Westside Foothill Oak Woodland-Grass-Chaparral
H. Mixed Mesic Hardwood Communities
I. Westside Foothill Mixed Hardwood-Conifer Forest

NON-FOREST RESOURCES

Chaparral

J. Westside Valley Front Foothill Chaparral
K. Westside Intermediate Mountain Chaparral
KK. Eastside Intermediate Mountain Chaparral
L. Eastside Valley and Basin Front Sagebrush Scrub

Grassland-Meadow-Marshland Complex

M. Subalpine Grassland
N. Intermediate Interior Valley Xeric Grassland
O. Mesic Meadow Complex
P. Freshwater Marshland

AGRICULTURAL AND RANGELAND RESOURCES

Q. Mesic Cultivated Croplands
R. Mesic Rangeland
S. Xeric Eastside Grassland-Scrub Rangeland

OTHER LANDSCAPE FEATURES

T. Forest Plantation Sites
U. Urban-Residential-Commercial Sites
V. Exposed Soil
W. Exposed Bedrock

WB. Basalt
WA. Andesite
WR. Rhyolite
WP. Pyroclastics
WG. Granite
WU. Ultrabasics
WS. Sedimentary
WM. Metavolcanics

HYDROLOGIC RESOURCES

X. Standing Water
Y. Running Water
Z. Snowpack

VEGETATION-TERRAIN RESOURCES
PERCENT COMPOSITION-RANGE
WITHIN HOMOGENEOUS DELINEATED AREAS

PERCENT COMPOSITION	CODE NUMBER
0 - 5	1
6 - 20	2
21 - 40	3
41 - 60	4
61 - 80	5
81 - 100	6

TABLE 4.3. DESCRIPTION OF MAJOR VEGETATION TYPES FOUND TO OCCUR WITHIN THE FEATHER RIVER WATERSHED

Forest Resources

Fir Forest (A)

This dense homogeneous closed canopy forest type generally dominated by red fir, with white fir, sugar pine, and lodgepole pine as codominants, occurs between 6000-9000+ feet elevation in the upper crest zone primarily within the westside region where mean annual precipitation ranges from 65-80 inches, and where mean annual summer and winter temperatures range from 73-85°F and 16-26°F, respectively. On the eastern part of the crest zone, where mean annual precipitation is less, the type is characterized by two fir communities, one dominated by red fir at high elevations (7000-8000 feet) and the other by white fir (6000-7000 feet). These types are confined to upper north and northeast exposures, and crests, and often include lodgepole pine as a subdominant.

Westside Intermediate Mountain Mixed Conifer (B)

The westside intermediate mountain mixed conifer forest is characterized by several forest communities dominated by ponderosa pine, douglas fir, sugar pine and white fir, in which incense cedar and lodgepole pine occur less frequently. The mixed conifer type predominantly occurs at intermediate elevations between 3500-7000 feet, with the more homogeneous Douglas fir and ponderosa pine dominated communities on the westside extending to the lower elevations, 1500 and 2500 feet, respectively, and the white fir dominated communities occurring at the higher elevations up to 6500 feet. Mean annual precipitation within the mixed mountain conifer type ranges from 55-80 inches, and mean annual summer and winter temperatures range from 80-93°F and 22-34°F, respectively.

Eastside Intermediate Mountain Mixed Conifer (BB)

This vegetation type is transitional between the eastside mountain mixed conifer and the eastside intermediate pine forests, and is characterized by the presence of lodgepole pine, white fir, incense cedar, ponderosa pine, Jeffery pine, and Douglas fir. It occurs on optimum sites predominately between 5000-7500 feet elevation, intermittently among the eastside pine forest types.

Eastside Intermediate Pine-Scrub Forest (C)

The eastside intermediate pine-scrub forest, occurring on less optimum sites to the east of the crest region, is characterized by a low tree density, open canopy, and is dominated by Jeffery pine, ponderosa pine, and lodgepole pine, with incense cedar and Douglas fir occurring infrequently. The understory matrix is dominated by either low sagebrush, mules ear, or xeric grassland. The pine-scrub forest occurs between 5000-6000 feet elevation, where mean annual precipitation is 25-50 inches and mean annual summer and winter temperatures range between 67-75°F and 10-18°F, respectively.

Eastside Northern Juniper Woodland (D)

The northern juniper woodland occurs where mean annual precipitation ranges from 10-30 inches at intermediate elevations between 4200-5600 feet, along the Great Basin Front on the eastside. Mean annual summer and winter temperatures range from 82-89°F and 10-20°F, respectively.

TABLE 4.3. (Continued)

Widely dispersed dominant tree species, include singleleaf pinyon, western juniper, and Jeffery pine. Big sagebrush, Utah and yellow penstemon characterize the understory matrix.

Eastside Timberland-Chaparral Complex (E)

This predominantly eastside vegetation type is characterized by an open canopy, where ponderosa pine and Jeffery pine dominates and incense cedar, Douglas fir, and white fir occur as co-dominants. The complex generally occurs from 6500-8000 feet elevation where mean annual precipitation ranges from 25-50 inches, and mean annual summer and winter temperatures range from 67-75^{o}F and 10-18^{o}F, respectively. The understory vegetation is characteristically dominated by green leaf manzanita.

Intermediate Mountain Xeric Hardwoods (F)

The xeric hardwood vegetation type is dominated by California black oak, Oregon white oak, pacific madrone, sierra chinkapin, pacific dogwood and serviceberry, with mountain chaparral and sierra current as understory. This generally closed canopy plant community occurs from 2500-6500 feet elevation and occupies mountainous exposed, xeric, and often rocky south and southwest slope aspects, intermingled with generally low density intermediate mountain mixed conifer types.

Westside Foothill Pine-Oak Woodland (G)

This vegetation type generally occurs between 400-3000 feet elevation on westside foothill slopes along the valley front. It may predominate on south and southwest aspects to a maximum elevation of 4000 feet. Mean annual precipitation within this type ranges from 15-40 inches, while mean annual summer and winter temperatures range from 75-96^{o}F and 29-42^{o}F, respectively. The pine-oak woodland type is characterized by sparse tree density, forming an open canopy where interior live oak, blue oak, Engleman oak, California white oak, canyon live oak, digger pine, and Coulter pine occur predominantly as overstory. Differing homogeneous understory dominants tend to segregate the pine-oak woodland type into the following plant communities: (1) the woodland-chaparral (GC), where valley front chaparral predominates as understory, (2) the woodland-grass (GG), where xeric annual grassland exists as understory, and the woodland-grass-chaparral (GGC), where both grass and chaparral intermix to form the understory matrix.

Mixed Mesic Hardwood Communities (H)

Mixed mesic hardwood communities occur within the broad 400-9000 feet elevational range throughout the watershed. At higher elevations within the crest region the mesic hardwood type is dominated by mountain alder, black cottonwood, and willow, and may occur as a riparian "stringer". These also may be associated with the mesic meadow complex within the red fir and mixed mountain conifer types. This mesic community also descends steep, north, northeast and east facing ravines from the crest to intermediate elevational zones where bigleaf maple, white alder, western dogwood, hazelnut, and California bay tend to predominate also. The mixed mesic hardwood type at lower elevations and along river and stream channels, flats at bottomland, is characteristically a mixed riparian hardwood community which generally includes a mixture of the above mentioned species plus California buckeye.

TABLE 4.3. (Continued)

Westside Foothill Mixed Hardwood-Conifer Forest (I)

This mixed, generally dense, vegetation type primarily occurs on north and northeast aspects between 500-3000 feet elevation where mean annual precipitation ranges from 40-55 inches. Important tree species include tan oak, California black oak, live oak, digger pine, coulter pine, Douglas fir, and ponderosa pine. The westside valley front chaparral forms an understory matrix where the canopy is open.

Non-Forest Resources

Westside Valley Front Foothill Chaparral (J)

This generally homogeneous foothill chaparral type occurs below 2500 feet on lower west, southwest and south slope aspects and ridges of the westside foothills where mean annual precipitation ranges from 15-30 inches and mean annual summer and winter temperatures range from 82-94°F and 29-45°F, respectively. The foothill chaparral type is dominated by chamise, several manzanita species, western mountain mahogany, and several scrub oaks, and is diverse in species composition.

Westside Intermediate Mountain Chaparral (K)

This often extensive homogeneous mountain chaparral type occurs from 4000-9000 feet elevation on drier exposed and often disturbed sites resulting from fire or logging. This vegetation type extends below 4000 feet forming a transitional phase uniting with the valley front chaparral. The mean annual precipitation range is variable among sites occupied by the intermediate mountain chaparral type. Mean annual summer and winter temperatures range from 82-94°F and 29-45°F, respectively. The mountain chaparral community may occur as an early successional stage after fire, thus occupying deep forest soil sites. The mountain chaparral community is primarily composed of greenleaf and pinemat manzanita, snowbrush, buckbrush, deerbrush, squaw carpet, mountain misery, huckleberry oak, and bitter cherry. The intermediate mountain chaparral often comprises the understory matrix within the westside mountain mixed conifer type.

Eastside Intermediate Mountain Chaparral (KK)

The eastside intermediate mountain chaparral is primarily characterized by its physiographic location where mean annual precipitation is less compared to westside types. The generally homogeneous eastside mountain chaparral is dominated by greenleaf manzanita and forms the understory matrix of the eastside timberland chaparral complex.

Eastside Valley and Basin Front Sagebrush Scrub (L)

This xeric plant community occasionally occurs on slopes below 4500 feet elevation on the eastside region, but is most extensive on the xeric valley flatland sites within the Sierra Valley and along the Great Basin edge adjacent to the watershed's eastern boundary. This low-density, sagebrush-scrub community is dominated by low sagebrush species, saltbrush, rabbitbrush, and bitterbrush. Bare ground, exposed rock rubble, and sparse xeric grasses characterize sagebrush sites. Mean annual precipitation ranges from 12-15 inches, and summer and winter temperatures range from 83-95°F and 8-27°F, respectively.

TABLE 4.3. (Continued)

Subalpine Grassland (M)

The subalpine grassland community generally occurs at higher elevations (6000+ feet) on mountain slopes. It usually is confined to homogeneous areas within other vegetation types, and is composed of perennial grasses, reedgrass, sedges, forbs fescue and bluegrass, in the high elevation northwestern Mt. Lassen region, the subalpine grassland occurs as extensive homogeneous areas on the mountain slopes.

Intermediate Interior Valley Xeric Grassland (N)

This generally homogeneous annual grassland is dominated by broomgrass and occurs on valley and flatland xeric sites where mean annual precipitation ranges from 15-35 inches. In areas of higher precipitation, excessively well drained sites result in xeric conditions. Mean annual summer and winter temperatures of xeric grassland sites vary within the watershed depending on location.

Mesic Meadow Complex (O)

This perennial plant community is generally confined to higher elevations (5500+ feet) within the red fir and mixed mountain conifer forest types. The mesic meadow complex occurs as smaller homogeneous areas in poorly drained protected mesic sites where mean annual precipitation ranges from 25-75 inches. The complex is composed of perennial bunch grasses, forbs, sedges and occasional aquatic species where freshwater springs and intermittent streams provide moisture recharge.

Freshwater Marshland (P)

This mesic plant community is characterized by dominant freshwater aquatic species including cattail, sedges, and rushes. It occurs at both shoreline areas surrounding standing freshwater and on flooded sites characterized by constant water recharge such as within the flooded flat bottomlands of the interior valleys, and particularly the Sierra valley to the eastern region.

Agricultural Resources

Mesic Cultivated Croplands (Q)

Principle crops within the interior valleys of the Feather River Watershed region include alfalfa, hay, and small grains. Fallow croplands often are planted in clover and grass and utilized as rangeland.

Mesic Rangeland (R)

The mesic rangeland is characterized by perennial grasses which are grazed throughout the hotter summer months. Mesic rangeland occurs within the interior valleys, and as small homogenous mesic units at higher elevations within forested areas.

Xeric Eastside Grassland-Scrub Rangeland (S)

This agricultrual range resource intergrades with the eastside sagebrush-scrub community, and is predominantly composed of sparse annual grasses and low sagebrush species.

false-color infrared, high altitude photos. Both monoptic and stereoscopic interpretation of the photos resulted in a regional vegetation/terrain map of the entire Feather River watershed (see Figure 4.2).

In addition, a color-coded version of the principal resource types within the Feather River watershed was made which illustrates the distribution of resources within the entire region (see Figure 4.3). Approximately 57.5 percent of the region is classified as conifer forest; 3.9 percent as hardwood forest; 5.1 percent as grassland-rangeland; 10.0 percent as chaparral; 5.3 percent as sagebrush-scrub; 10.0 percent as exposed rock and soil; and 5.8 percent as standing water.

The vegetation/terrain type maps illustrated in Figures 4.2 and 4.3 not only were useful while analyzing ERTS-1 imagery but also have proven to be invaluable to the Plumas County Planning Commission, Quincy, California. The Planning Commission's interest in the level of interpretation proficiency, mapping accuracy and mapping techniques, as well as the versatility for potential uses of the maps in resource management and planning, has been exceptional since few comprehensive resource maps of the region exist. In another instance, personnel of the California Department of Parks and Recreation used these same techniques in mapping the Lake Oroville subregion. They considered the high altitude photography an excellent tool for periodic vegetation type mapping and change detection analysis, imperative in aiding management decisions.

4.2.3 Evaluation of Components of the ERTS-1 System

4.2.3.1 Evaluation of MSS Bands 4, 5 and 7 and a Color Composite Print

Preliminary manual interpretation work done on ERTS-1 imagery was concentrated on evaluating the Multispectral Scanner System (MSS). The following MSS single bands were investigated for gross informational content: green, no. 4 (0.5-0.6 μm); red, no. 5 (0.6-0.7 μm), infrared, no. 7 (0.8-1.1 μm). In addition, a false-color composite print (made from MSS bands 4-5-7) provided by NASA-Goddard was analyzed. The 1:1,000,000 scale single band, single date (July 25, 1972) black-and-white transparency images were professionally enlarged to a 16 x 20 inch print format. The color composite image used in this initial evaluation was a third generation copy enlargement (16 x 16 inch) derived from an available 9 x 9 inch color print of the region. Uniformly appearing areas were delineated on overlays of these four enlarged images by two trained photo interpreters.

Evaluations of these delineations done on each MSS single band image and also on the color composite image were accomplished by direct visual comparison with analogous areas seen on the compiled ground control maps, including lithology, drainage, elevation, and precipitation.

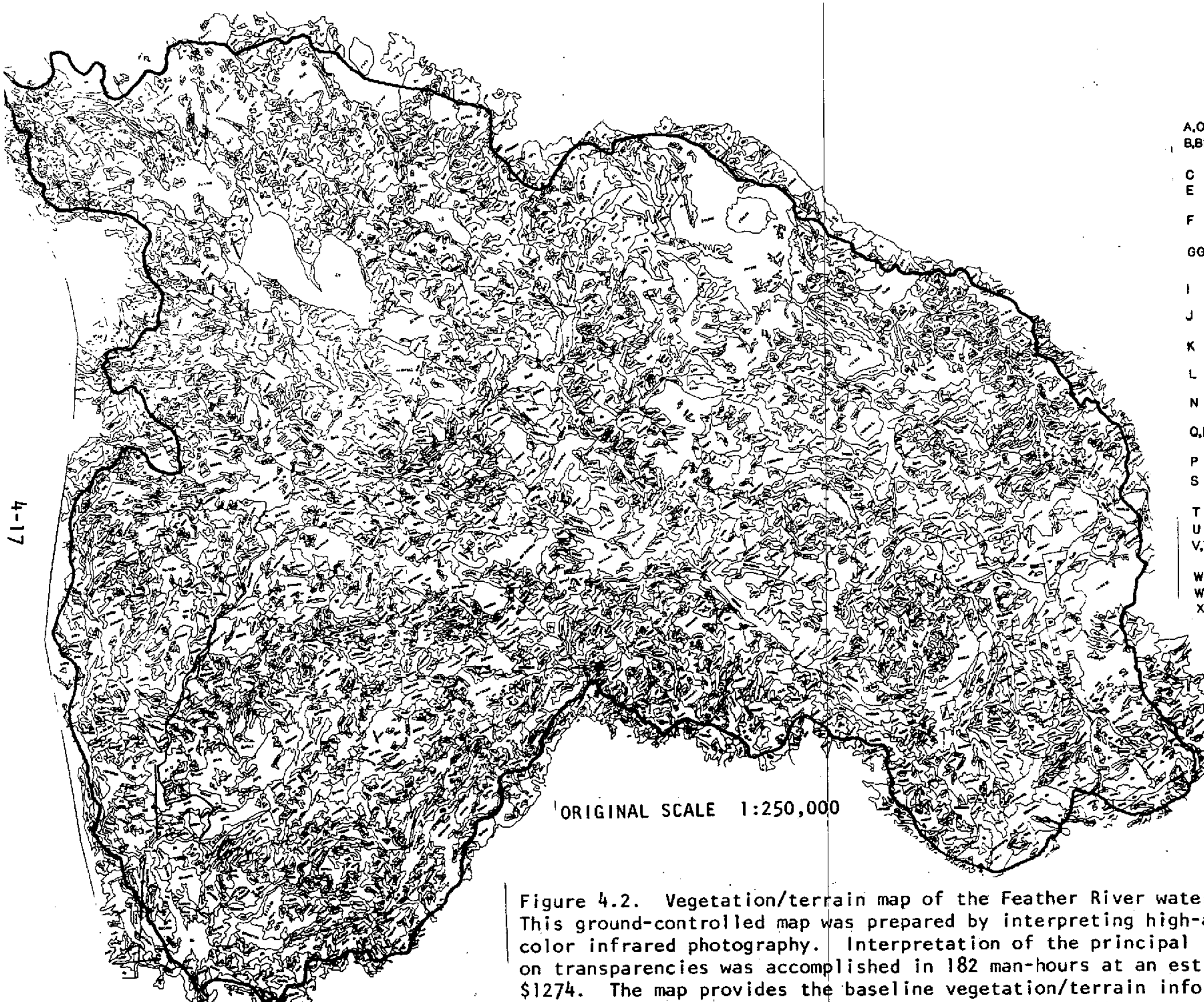


Figure 4.2. Vegetation/terrain map of the Feather River watershed region. This ground-controlled map was prepared by interpreting high-altitude, false-color infrared photography. Interpretation of the principal resource types on transparencies was accomplished in 182 man-hours at an estimated cost of $1274. The map provides the baseline vegetation/terrain information necessary for ERTS-1 map data comparisons. The areas delineated can be related to the classification scheme that is presented in Table 4.2.

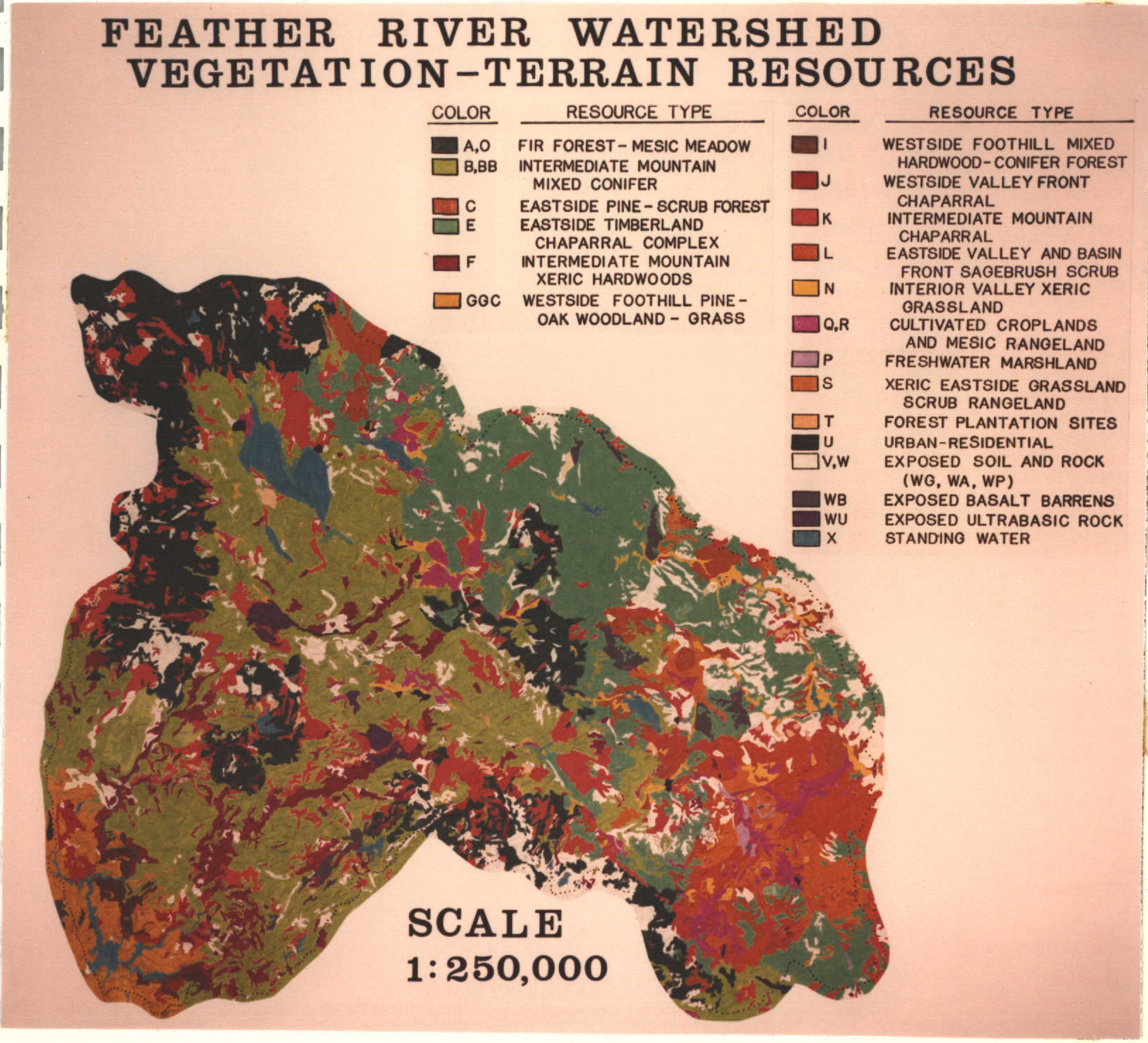


Figure 4.3. Feather River watershed vegetation/terrain resources color coded by principal types. Conifer forest comprises approximately 57.5 percent of the region; hardwoods, 3.6 percent; grassland-rangeland, 5.1 percent; exposed rock and soil, 10.0 percent; and standing water, 5.8 percent.

The evaluation process centered on assessing the ability of the analyst to both detect and identify resources as seen on the ERTS-1 imagery. The comparisons made between the ERTS-1 interpretation results and ground-control maps allowed for the preparation of a feasibility diagram (see Table 4.4). The diagram presented in Table 4.4 shows the general interpretability of wildland resources as seen on ERTS-1 imagery. High altitude false-color infrared photography also was evaluated.

The feasibility diagram indicates that the skilled interpreter can <u>detect</u> wildland resources and analogous cover-type indicators acceptably well on ERTS-1 imagery; however, object <u>identification</u> is more difficult. Specifically, the MSS green band, no. 4, appears most useful for the eastside valley and basin front sagebrush-scrub identification, as well as for main highway and logging road identification, where detectable. The MSS red band, no. 5, has been assessed as useful in the identification of fir forest, intermediate interior valley xeric grassland, mesic cultivated croplands, mesic rangeland, xeric grassland-scrub rangeland, sedimentary bedrock, standing water, highways, and logging roads. Mesic cultivated croplands and standing water are clearly identifiable on the infrared band, no. 7. On a regional basis, these preliminary results indicate that an interpreter can identify the following wildland resources on the MSS 4-5-7 false-color composite image: intermediate interior valley xeric grassland, fresh water marshland, mesic cultivated croplands, mesic rangeland, xeric eastside grassland-scrub rangeland, exposed basalt bedrock, sedimentary rock, and standing water.

4.2.3.2 <u>Evaluation of a Color Composite Transparency</u>

An ERTS-1 color composite transparency was evaluated within the 400,000 acre Davis Lake study area which is located on the eastern side of the Feather River watershed. An interpretation test using manual techniques was conducted to assess the ability of two interpreters to use an ERTS-1 image interpretation key (see Figure 4.4) and additional resource descriptors while identifying and classifying wildland resources within the eastside management zone. Results of this interpretation test indicate that both interpreters were about <u>65 percent</u> proficient, in interpreting all the principal resource types present (see Table 4.5).

Both interpreters correctly identified all standing water bodies (X), and showed moderately high proficiency (>60 percent) in correctly identifying fir forest (A), eastside timberland-chaparral forest (E), mountain chaparral (KK), eastside valley and basin front sagebrush scrub (L), cultivated croplands (Q), mesic rangeland (R), xeric eastside grassland scrub rangeland (S), and exposed basalt. Among these resource type identifications, commission errors were generally low (35 percent) and omission errors were also generally low. Marginal interpreter

TABLE 4.4. PRELIMINARY INDICATORS OF THE FEASIBILITY OF WILDLAND LANDSCAPE FEATURE DETECTION AND IDENTIFICATION WITHIN THE FEATHER RIVER WATERSHED REGION ON HIGH ALTITUDE AIRCRAFT AND ERTS-1 IMAGERY.

LEGEND

- ●●● EASILY DETECTABLE
- ●● MARGINALLY DETECTABLE
- ● NOT DETECTABLE

- ●●● EASILY IDENTIFIABLE
- ●● MARGINALLY IDENTIFIABLE
- ● NOT IDENTIFIABLE

IMAGERY PARAMETERS										
VEHICLE	HIGH ALT. RB57		ERTS-1		ERTS-1		ERTS-1		ERTS-1	
SENSOR SYSTEM	RC-8 CAMERA		MSS BAND #4		MSS BAND #5		MSS BAND #7		MSS BANDS 457	
MISSION # & DATE[a]	MX 139(7-25-70)		(7-25-72)		(7-25-72)		(7-25-72)		(7-25-72)[b]	
ORIGINAL IMAGE TYPE	FALSE COLOR IR		B&W TRANS.		B&W TRANS.		B&W TRANS.		CIR ENHAN. TR.	
INTERPRETED IMAGE TYPE	CIR TRANS.		B&W PRINT		B&W PRINT		B&W PRINT		COLOR PRINT[c]	
ORIGINAL FORMAT	9 X 9 in.		9 X 9 in.		9 X 9 in.		9 X 9 in.		9 X 9 in.	
INTERPRETATION FORMAT	9 X 9 in.		16 X 20 in.		16 X 20 in.		16 X 20 in.		16 X 16 in.	
IMAGE SPECTRAL RANGE	0.4 - 0.9μm		0.5 - 0.6μm		0.6 - 0.7μm		0.8 - 1.1μm		.5-.7 & .8-1.1μm	
ORIGINAL IMAGE SCALE	1:120,000		1:1,000,000		1:1,000,000		1:1,000,000		1:1,000,000	
OBJECT RESOLUTION	20-30 FT.		200-300 FT.		200-300 FT.		200-300 FT.		200-300 FT.	
INTERPRETATION RESULTS	D*	I**	D*	I**	D*	I**	D*	I**	D*	I**
FOREST RESOURCES										
Coniferous Forests	●●●	●●●	●●	●●	●●	●●	●●	●	●●●	●●
A. High Elevation Red Fir Forest	●●●	●●●	●●	●	●●●	●●●	●	●	●●●	●●
B. Westside Intermediate Mountain Conifer	●●●	●●●	●●	●●	●●●	●●	●●	●	●●	●●
BB. Eastside Intermediate Mountain Mixed Conifer	●●	●●	●●	●	●●	●	●	●	●	●
C. Eastside Intermediate Pine-Scrub Forest	●●●	●●●	●●●	●●	●●●	●●	●	●	●●	●●
D. Eastside Northern Juniper Woodland	●●	●●	●	●	●	●	●	●	●	●
E. Eastside Timberland-Chaparral Complex	●●●	●●●	●●	●●	●●●	●●	●	●	●●●	●●
Hardwood Forests	●●●	●●●	●●	●	●●	●●	●	●	●●	●
F. Intermediate Mountain Xeric Hardwoods	●●●	●●●	●●	●	●●	●	●	●	●●	●●
G. Westside Foothill Pine-Oak Woodland	●●●	●●●								
GG. Westside Foothill Oak Woodland-Grass	●●●	●●●								
GC. Westside Foothill Oak Woodland-Chaparral	●●●	●●●								
GGC. Westside Foothill Oak Woodland-Grass-Chaparral	●●●	●●●								
H. Mixed Mesic Hardwood Communities	●●●	●●●	●	●	●	●	●	●	●	●
I. Westside Foothill Mixed Hardwood-Conifer Forest	●●●	●●●								
NON-FOREST RESOURCES										
Chaparral	●●●	●●●	●●	●●	●●	●●	●●	●	●●●	●●
J. Westside Valley Front Foothill Chaparral	●●●	●●●								
K. Westside Intermediate Mountain Chaparral	●●●	●●●	●●	●	●●●	●●	●●	●	●●●	●●
KK. Eastside Intermediate Mountain Chaparral	●●●	●●●	●●	●●	●●●	●●	●●	●	●●●	●●
L. Eastside Valley and Basin Front Sagebrush Scrub	●●●	●●●	●●●	●●●	●●●	●●	●	●	●●●	●●
Grassland-Meadow-Marshland Complex	●●●	●●●	●●	●	●●	●	●	●	●●●	●●
M. Subalpine Grassland										
N. Intermediate Interior Valley Xeric Grassland	●●●	●●●	●●●	●●	●●●	●●●	●	●	●●●	●●●
O. Mesic Meadow Complex	●●●	●●●	●●	●	●●	●●	●	●	●	●
P. Freshwater Marshland	●●●	●●●	●●●	●●	●●●	●●	●●	●	●●●	●●●
AGRICULTURAL AND RANGELAND RESOURCES										
Q. Mesic Cultivated Croplands	●●●	●●●	●●	●	●●●	●●●	●●●	●●●	●●●	●●●
R. Mesic Rangeland	●●●	●●●	●●	●●	●●	●●●	●	●	●●	●●●
S. Xeric Eastside Grassland-Scrub Rangeland	●●●	●●	●●●	●●	●●●	●●●	●	●	●●●	●●●
OTHER LANDSCAPE FEATURES										
T. Forest Plantation Sites	●●●	●●●	●●●	●●	●●●	●●	●	●	●●●	●●
U. Urban-Residential-Commercial Sites	●●●	●●●	●●	●	●●●	●	●	●	●●	●
V. Exposed Soil	●●●	●●●	●●	●●	●●	●●	●	●	●●	●●
W. Exposed Bedrock	●●●	●●	●●●	●●	●●	●●	●	●	●●	●●
WB. Basalt	●●●	●●●	●●	●	●●	●	●	●	●●●	●●●
WA. Andesite	●●●	●●	●●	●	●●●	●●	●	●	●●	●
WR. Rhyolite	●●	●●								
WP. Pyroclastics	●●●	●●	●●	●	●●	●	●	●	●●	●●
WG. Granite	●●●	●●●	●●	●	●●●	●●	●	●	●●	●●
WU. Ultrabasics	●●●	●●●	●●	●	●●●	●	●	●	●●●	●●
WS. Sedimentary	●●●	●●●	●●	●	●●●	●●●	●●	●	●●	●●●
WM. Metavolcanics	●●	●●	●	●	●	●	●	●	●	●
HYDROLOGIC RESOURCES										
X. Standing Water	●●●	●●●	●●	●●	●●●	●●●	●●●	●●●	●●●	●●●
Y. Running Water	●●●	●●●	●	●	●●	●●	●	●	●●	●●
Z. Snowpack	●●●	●●●								
MISCELLANEOUS FEATURES										
ZA. Recent Fire Scar	●●●	●●●	●	●	●●	●	●●●	●●	●●●	●●
ZB. Main Highway	●●●	●●●	●●●	●●●	●●●	●●●	●	●	●●●	●●
ZC. Landslide Scar	●●●	●●●	●●	●	●●●	●	●	●	●●	●●
ZD. Logging Roads	●●●	●●●	●●	●●●	●●●	●●●	●	●	●●	●●

* DETECTION .... THE ABILITY TO DISCRIMINATE AN IMAGE ENTITY FROM THE SURROUNDING TONE MATRIX.

** IDENTIFICATION .... THE ABILITY TO CLASSIFY AND ASSIGN A NAME TO AN IMAGE DETERMINED BY ITS UNIQUE CHARACTERISTICS SUCH AS COLOR, TONE, TEXTURE, SHAPE, PATTERN, SIZE, ASSOCIATION OR OTHER QUALITY.

[a] Feasibility of image identification includes consideration of sequential imagery.
[b] MSS color-combined enhanced image transparency.
[c] The enlarged print used in this interpretation was fifth generation.

1. Color is not red; color is dark blue to blue black.
   2. Color dark blue; resource boundary distinct (see test cell No. 35) .... STANDING WATER (LAKE OR RESERVOIR) (X)
   2. Color moderately dark blue; resource boundary not necessarily distinct.
      3. Color is more saturated with blue, light blue, boundary distinct .... STANDING WATER, SHALLOW POND WITH HIGH SEDIMENT OR SALT CONTENT (X)
      3. Color is less saturated; boundary indistinct; resource often mottled with light tones and red colorations .(No. 52) .... EXPOSED BASALT BEDROCK (WB)
1. Color is red, ranging from very pale or light gray-red, light pruplish gray-red or other pale color variants, to moderate strong, bright, saturated or dark red, orange-red or purplish red.
   4. Colors are mostly moderately dark to strongly saturated or dark red (Nos. 4,55,84,82,144,294,252); some tones appear bright (Nos. 143,199, 273)
      5. Red color tones are moderately dark (Nos. 79,93,160), but color may be strong or saturated and red to red-orange (No. 188). The resource is often mottled with pale lighter tones (Nos. 93, 267) .... EASTSIDE INTERMEDIATE MOUNTAIN CHAPARRAL (KK)
      5. Red color tones are mostly dark and colors range from a dark purplish-red (Nos. 49, 85) to dark strong red (Nos. 156, 206, 25, 28) and dark orange-red (Nos. 144, 31, 214)
         6. Mean Annual Precipitation (MAP) predominently ranges 30-50 inches; Color tone is dark purplish red to dark purplish brownish red (Nos. 4, 274). Resource occurs in smaller scattered areas.
            7. Elevational range: 7000 - 8000 feet (+) .... FIR FOREST (RED FIR) (A)
            7. Elevational range: 5000 - 7000 feet (±) .... FIR FOREST (WHITE FIR) (A)
         6. MAP ranges from less than 40 inches.
            8. MAP ranges 18 - 30 inches; color is moderate red, moderate purplish red (Nos. 95, 221), to light purplish red (Nos. 29, 115); Elevational range 5000 - 6000 feet .... EASTSIDE INTERMEDIATE PINE-SCRUB FOREST (C)
            8. MAP ranges 18 - 35 inches; color is moderately dark, saturated, or strong.
               9. Color is mostly strong orange-red, strongly red (No. 144) or purplish red (No. 217). Elevational range is 5000 - 7000 feet; Resource type is extensive .... EASTSIDE TIMBERLAND CHAPARRAL COMPLEX
               9. Color is less orange-red, more strongly red to moderate purplish-red (Nos. 9, 80, 256); elevational range is 4000 - 7000 feet; this resource type is transitional .... EASTSIDE INTERMEDIATE MOUNTAIN MIXED CONIFER (BB)
   4. Colors are moderately light (Nos. 171, 228) and bright (No. 122) to very bright (No. 118) and light (No. 243) in tone, <u>except</u> for dark pinkish gray areas. (Nos. 10, 131, 174).
      10. Colors range from purplish red-gray (No. 174) to gray-pink (No. 192); Colors are low in saturation
         11. Color tone relatively dark purplish red-grey (No. 174) to moderately dark pinkish grey (No. 171) (high to low density, respectively); saturation is low; elevational range 4000 - 6000 feet .... EASTSIDE VALLEY AND BASIN FRONT SAGEBRUSH-SCRUB (L) (L-6,Dense) (L-4,Sparse)
         11. Color tone lighter; light or pale purplish gray (No. 127); Elevational range 4000 - 5000 feet .... XERIC EASTSIDE GRASSLAND SCRUB RANGELAND (S)
      10. Colors range from light pink to pale orange-red.
         12. Color tone is varied; color saturation may be strong, but generally is not.
            13. Color tone is moderately light (No. 47) to very light (No.63); Resource associated wtih bright red to moderate orange-red mesic rangeland areas. This type is not extensively homogeneous within this region .... INTERMEDIATE INTERIOR VALLEY XERIC GRASSLAND (N)
            13. Color tone is less than moderately light.(No. 47)
               14. Color saturation is moderate (Nos. 38,218, 5, 94); Color tone is moderate but may be <u>very</u> light(No.182) where soil is completely void of vegetation cover .... EXPOSED SOIL OR ROCK WITH SPARSE GRASS OR CHAPARRAL COVER (V), (W), (V-KK).
               14. Color saturation is moderately low; tones are moderate; color may be grayish (No.130) or pinkish grey(Nos.128, 192)..... MIXED GRASSLAND SCRUB RANGELAND, S(R,L,N)
         12. Color tone is moderate to light; color saturation is usually strong to bright; color appears strong pink, red or red orange.
            15. MAP ranges 10 - 40 inches.
               16. Elevation ranges 4000 - 7000 feet; Map ranges 20 - 30 inches; resource mix varied, occurs as pale grey-red N(S) (No.33) or slightly brighter red N(R) (No. 65); resource type varied and not extensive .... MIXED XERIC GRASSLAND N(R), N(L), N(S)
               16. Elevation ranges 4000 - 7000 feet
                  17. Elevation ranges 4000 - 5000 feet; pattern discernible as small squares or areas with right angle corners (No.176). MAP ranges 10 - 14 inches; color is bright to moderate red or red- orange (No.122) .... CULTIVATED CROPLANDS (Q)
                  17. Elevation varied; right angular pattern not discernible.
                     18. MAP ranges 10 - 40 inches; elevation ranges 4000 - 6000 feet; color is red-orange often occurring as strong bright red of pink areas within extensive dark red or purplish-red areas (No. 194); resource may appear elongate .... MESIC RANGELAND (R)
                     18. MAP ranges 14 - 35 inches.
                        19. Elevation ranges 5000 - 7000 feet; MAP 18 - 35 inches; very few extensive homogeneous areas of this resource occur within this region .... INTERMEDIATE MOUNTAIN XERIC HARDWOODS (F)
                        19. Elevation ranges 4000- 5000 feet; MAP ranges 12 - 16 inches; color mottled red to dark purplish red (No, 124, 170); resource often elongate occurring within gray areas; associated with bright strong red areas (No. 229).... MARSHLAND (P)

Figure 4.4. ERTS-1 image interpretation key to wildland resources within the Davis Lake study area of the Feather River watershed region.

TABLE 4.5. RESULTS OF THE INTERPRETATION TEST OF SPECIFIC VEGETATION/TERRAIN TYPES USING AN ERTS-1 COLOR COMPOSITE TRANSPARENCY.

SPECIFIC RESOURCE TYPE	NO. TEST CELLS	INTERPRETER IDENTIFICATION	NO. INDICATED	NO. OMITTED	NO. CORRECT	NO. COMMISSION ERROR	PERCENT OMISSION	PERCENT COMMISSION (I)[c]	PERCENT COMMISSION (II)[d]	PERCENT CORRECT
A	10	A[a]	7	3	7	0	30	0	0	70
		B[b]	9	4	6	3	40	30	33	60
BB	10	A	4	8	2	2	80	20	50	50
		B	2	9	1	1	90	10	50	10
C	9	A	13	4	5	8	44	88	61	55
		B	11	4	5	6	44	66	54	55
E	35	A	38	5	30	8	14	22	21	85
		B	53	5	30	23	14	65	43	85
F	3	A	1	3	0	1	100	33	100	0
		B	0	3	0	0	100	0	0	0
KK	29	A	32	6	23	9	20	31	28	79
		B	24	10	19	5	34	17	20	65
L	24	A	30	2	22	8	8	33	26	91
		B	19	12	12	7	50	29	36	50
N	9	A	0	9	0	0	100	0	0	0
		B	7	5	4	3	55	33	42	44
P	3	A	1	2	1	0	66	0	0	33
		B	1	2	1	0	66	0	0	33
Q	5	A	3	2	3	0	40	0	0	60
		B	3	2	3	0	40	0	0	60
R	21	A	23	3	18	5	14	23	21	85
		B	19	5	16	3	23	14	15	76
S	16	A	14	6	10	4	37	25	28	62
		B	23	0	16	7	0	43	30	100
V	6	A	5	5	1	4	83	66	80	16
		B	5	4	2	3	66	50	60	33
W	8	A	2	7	1	1	87	12	50	12
		B	0	8	0	0	0	0	0	0
WB	4	A	4	0	4	0	0	0	0	100
		B	3	2	2	1	50	25	23	50
X	6	A	6	0	6	0	0	0	0	100
		B	6	0	6	0	0	0	0	100
TOTAL	198	A	183	55	133	50	32	25	27	67
		B	185	75	123	62	37	31	33	62

[a] Results for Interpreter A

[b] Results for Interpreter B

[c] Error based on number of type present

[d] Error based on number of a type indicated

proficiency was demonstrated for resource types BB, C, N, P, V, and W, while neither interpreter correctly detected nor identified the few hardwood types presented. The interpretation test results compared well with preliminary feasibility indicators illustrated in Table 4.4 except for resource types L, KK, E, and A which were more easily identifiable than expected. In most cases, difficulty was encountered in distinguishing among V,W, and N resource types; A, BB, and E resource types; and C, KK, and R resource types. From the test results illustrated in Table 4.5, it is apparent that the most difficult types to detect were BB, F, P, V, C, and W. Proficiency in correctly identifying these resources was low.

In addition, test results indicate high interpreter proficiency in interpreting broad comprehensive resource types, including coniferous forest, cultivated croplands, standing water bodies, sagebrush types, mesic rangeland-marshland types, and mountain chaparral (see Table 4.6). Exposed soil and bedrock proved marginally identifiable. Both xeric grassland areas and hardwood forests were virtually undetectable. Among the comprehensive resource types present in the Davis Lake study area, both interpreters were about 70 percent correct overall in their interpretations.

In summary, the interpretation test results derived from an ERTS-1 color composite transparency taken on a single date indicate the relative interpretability of major resources within the Davis Lake study area of the Feather River watershed region. High proficiency in resource identification was exhibited by both interpreters for nine specific resource types. This indicates that the photo interpretation key prepared for the test was indeed valid for these resource types. As expected, certain resource types were not mutually exclusive. Therefore, due to heterogeneity within certain types, several of these types were difficult to separate and identify and often were confounded in the interpretation. It would be expected, however, that interpretation proficiency could be improved if either (1) the key were more explicit, (2) multidate imagery were used, or (3) image enhancements were used, thus increasing the color or tone contrast between resource types having similar reflectance characteristics.

4.2.3.3 Evaluation of Color Composite and Enhancements

A series of quantitative image interpretation tests were carried out to determine which of several types of ERTS-1 imagery, including color composites, would be optimal for classifying commercial conifer forests in the Feather River watershed. Four image types, enlarged to an approximate scale of 1:250,000 were tested: (1) band no. 5 (October 1, 1972), (2) a color composite made photographically using band nos. 5 and 7 (August 31, 1972), (3) a color composite made photographically using band nos. 4, 5, and 7 (August 31, 1972), and (4) a color electronic enhancement made from the digital tapes for band nos.

TABLE 4.6. RESULTS OF THE INTERPRETATION TEST OF BROAD VEGETATION/TERRAIN TYPES USING AN ERTS-1 COLOR COMPOSITE TRANSPARENCY.

COMPONENTS	A,BB,C,E		F,H		KK,K		N,N(V)		Q		R,P		L,S		V,W,WB		X			
COMPREHENSIVE RESOURCE	CONIFEROUS FOREST		HARDWOOD FOREST		MOUNTAIN CHAPARRAL		XERIC GRASSLAND		CULTIVATED CROPS		MESIC RANGELAND		SAGEBRUSH SCRUB		EXPOSED SOIL		STANDING WATER		TOTALS	
NO. TEST CELLS	71		4		31		17		4		23		44		10		6		210	
INTERPRETER ID	A[a]	B[b]	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
NO. CORRECT	57	60	0	0	23	19	0	4	4	3	22	17	36	32	7	4	6	6	155	145
NO. COMMISSION	6	15	1	0	9	5	0	3	0	0	4	4	7	8	5	3	0	0	32	38
NO. INDICATED	63	75	1	0	32	24	0	7	4	3	26	21	43	40	12	7	6	6	187	183
NO. OMITTED	14	11	4	4	8	12	17	13	0	1	1	6	8	12	3	6	0	0	55	65
PERCENT OMITTED	19	15	100	100	25	38	100	76	0	25	4	26	18	27	30	60	0	0	26	30
PERCENT COMMITTED[c]	8	21	25	0	29	16	0	17	0	0	17	23	15	18	50	30	0	0	15	18
PERCENT COMMITTED[d]	9	20	100	0	28	20	0	42	0	0	15	19	16	20	41	42	0	0	17	20
PERCENT CORRECT	80	84	0	0	74	61	0	23	100	75	95	73	81	72	70	40	100	100	73	69

[a] Results for Interpreter A

[b] Results for Interpreter B

[c] Error based on number of type present

[d] Error based on number of a type indicated

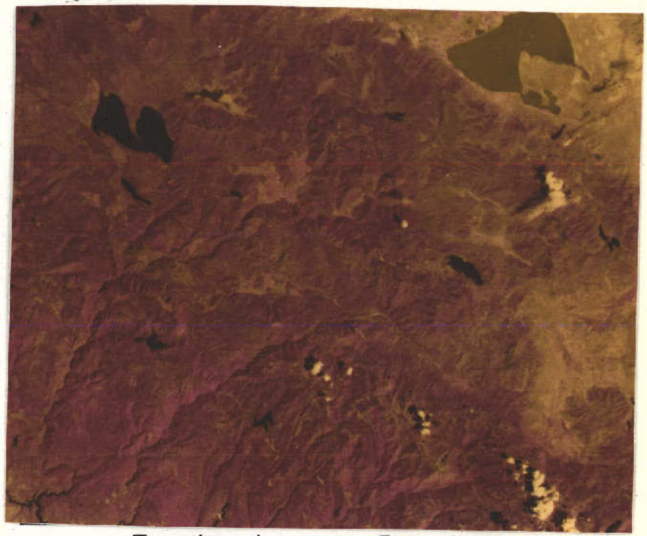
4, 5, and 7 (August 13, 1973). These image types (see Figure 4.5) were chosen for testing for the following reasons: (1) the spectral sensitivity of the band no. 5 image is similar to that of the conventional panchromatic photography now generally used by the U.S. Forest Service and other agencies for purposes of classifying forest lands, (2) the two-band photographic composite appeared to give good discrimination between vegetated and non-vegetated areas, (3) the three-band photographic composite is very similar to that produced by NASA at the Goddard facility, and (4) the three-band electronic enhancement appeared to increase the contrast between vegetation types. (A complete description of the techniques used to produce the photographic composites and the electronic enhancements can be found in the May 31, 1973 and November 30, 1972 Type 1 progress reports, respectively.) Due to the unavailability of acceptable imagery and digital tapes from the same ERTS overpass, three different dates of data were required. However, since no major phenological changes in the vegetation occurred during this period, it was felt that the use of the different dates would not introduce confounding errors into the quantitative tests.

For the purpose of testing and evaluating the imagery, a Latin Square Analysis of Variance design was utilized. The Feather River watershed test site was divided into four areas, and four interpreters were selected to evaluate the four image types. The three types of interpretation factors involved -- interpreters, image types, and areas -- were randomly allocated such that each area was examined by all four interpreters using a different image type. Each interpreter examined all four image types, and each interpreter looked at each area only once (Figure 4.6). This simple design is very efficient because (1) it reduces the number of interpreters required by eliminating the bias that occurs when an interpreter is continually retested on one area with image types and (2) it accounts for the variability due to the three interpretation factors.

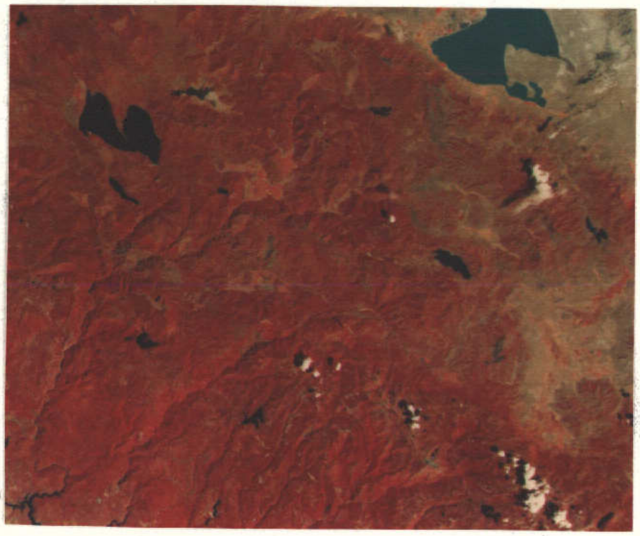
Four hundred twenty five points were randomly located on one set of test imagery, and these points were subsequently transferred to the other three image types. The density of commercial conifers surrounding these points (15 acre minimum size) was determined from 1:120,000 scale, high-altitude aircraft false-color infrared transparencies. The points were grouped into four stocking categories: (1) non-stocked, (2) low stocked (less than 10,000 bd. ft./acre), (3) medium stocked (10,000 - 20,000), and (4) high stocked (greater than 20,000 bd. ft./acre). The interpreters trained themselves on the areas surrounding 83 points and then classified the areas surrounding the remaining 342 points.

The interpretation test results, expressed as mean percent correct, type I error, and type II error are shown in Table 4.7 where:

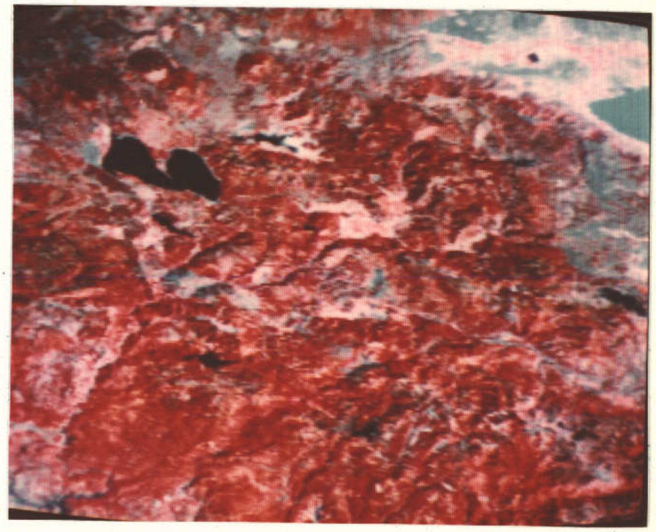
Band no. 5



Two band, nos. 5 and 7,
Photographic Composite



Three band, nos. 4, 5, and
7, Photographic Composite



Three band, nos. 4, 5, and
7, Electronic Enhancement

Figure 4.5. These four ERTS-1 images were used in a quantitative test to determine which would be most suitable for classifying commercial conifer forests in the Feather River watershed. A complete description of the techniques used to make the photographic enhancements can be found in the May 31, 1973 Type I progress report. Likewise, a description of Prof. Algazi's electronic enhancement techniques can be found in Chapter 8 of this report.

Image Type / Interpreter	(1)	(2)	(3)	(4)
A	I	IV	III	II
B	II	III	I	IV
C	IV	I	II	III
D	III	II	IV	I

Figure 4.6. The allocation of four image types (1, 2, 3, and 4), four interpreters (A, B, C, and D), and four test areas (I, II, III, and IV) for a Latin Square Analysis. Note that each interpreter examines each test area only once, thus eliminating the bias that frequently occurs when an interpreter is retested on the same area with different image types.

TABLE 4.7. RESULTS OF THE INTERPRETATION TEST OF CLASSIFYING FOREST LANDS USING ERTS-1 COLOR COMPOSITES AND ENHANCEMENTS.

	Image Type	% Correct	Image Type	% Type I Error	Image Type	% Type II Error
TOTAL CONIFER --						
	(4)	51.62	(4)	48.38	(4)	48.48
	(2)	50.27	(2)	49.73	(2)	49.73
	(3)	46.52	(3)	53.48	(3)	53.48
	(1)	41.41	(1)	58.59	(1)	58.59
F Ratio		6.039		6.039		6.039
Sig. diff. @ .10		yes		yes		yes
NON STOCKED CONIFER --						
	(1)	46.21	(1)	46.21	(2)	16.83
	(4)	45.86	(4)	54.14	(3)	20.83
	(2)	41.37	(2)	58.63	(1)	29.31
	(3)	39.15	(3)	60.85	(4)	43.41
F Ratio		.884		.884		6.298
Sig. diff. @ .10		no		no		yes
LOW STOCKED CONIFER --						
	(3)	39.25	(3)	60.25	(2)	43.90
	(2)	37.94	(2)	62.06	(3)	49.24
	(4)	37.50	(4)	62.50	(4)	55.26
	(1)	32.66	(1)	67.34	(1)	68.39
F Ratio		1.492		1.492		1.782
Sig. diff. @ .10		no		no		no
MEDIUM STOCKED CONIFER--						
	(2)	55.31	(2)	44.69	(4)	55.11
	(3)	45.74	(3)	54.26	(2)	57.95
	(4)	42.18	(4)	57.82	(3)	63.83
	(1)	38.09	(1)	61.91	(1)	68.30
F Ratio		.034		.034		2.80
Sig. diff. @ .10		no		no		no
HIGH STOCKED CONIFER --						
	(2)	71.89	(2)	28.11	(4)	40.65
	(4)	58.51	(4)	41.49	(2)	42.45
	(3)	58.47	(3)	41.53	(3)	51.52
	(1)	46.32	(1)	46.32	(1)	52.40
F Ratio		2.699		2.699		30.215
Sig. diff. @ .10		no		no		yes

Note: Image types included: (1) band no. 5, (2) two band, nos. 5 and 7, photographic composite, (3) three band, nos. 4, 5, and 7, photographic composite, and (4) three band, nos. 4, 5, and 7, electronic enhancement.

$$\text{percent correct} = \frac{\text{number of correct interpretations of a resource type}}{\text{total number of a resource type present}} \times 100$$

$$\text{percent type I (omission) error} = 1 - \text{percent correct}$$

$$\text{percent type II (commission) error} = \frac{\text{number of incorrect interpretations of a resource type}}{\text{total number of a resource type indicated by the interpreter}} \times 100$$

In the event that the difference between the groups' means were statistically significant the means were ranked using Duncan's multiple range test.

As shown in Table 4.7, the two most accurate classifications of total commercial conifer were accomplished using (1) the electronic enhancement and (2) the two-band photographic composite, with the relatively high values for percent correct of 51.62 and 50.27, respectively. The interpretation results for the other two images -- the three-band photographic composite and the band no. 5 -- were statistically poorer. It should be noted that although the entire range of values -- 41.41 to 51.67 -- is relatively short, a statistical difference was present in the analysis. This is due to the use of the Latin Square Design which accounts for the major sources of variability in photo interpretation tests. The only other statistically significant differences occurred for non-stocked and high stocked conifer, type II error. In the first case, the two-band and the three-band photographic composites had the lowest errors while the electronic enhancement had the highest error of all images tested. The high type II error associated with the electronic enhancement is also evident in the low stocked conifer category. Most of this error occurs because even on the enhanced images, these two low vegetation densities have almost identical appearances and it was impossible for the interpreters to consistently distinguish between the two.

Overall, the accuracy of the image interpretation was low and the associated error was relatively high (see Table 4.7). It should be noted, however, that 73 percent of the errors occurred by classifying a particular point as either one density class above or below that which was considered "ground truth" (see Figure 4.7). In fact, 83 percent of all points were interpreted either correctly or within one density level of what was "correct". The transition between different density classes of conifer forest is rarely abrupt. This is important for one to realize when evaluating the usefulness of ERTS-1 imagery for stratifying forest lands as a step toward the making of inventories. The error associated with the frequent misplacement of a stratum line within the transition zone between two density classes

P.I. WCD

		GROUND DATA				Total Sample	Type II Error
		N	L	M	H		
INTERPRETER RESULTS	N	35	16	4	3	58	23
	L	23	28	27	6	84	56
	M	21	21	48	35	125	77
	H	3	7	20	45	75	30
Total Points		82	72	99	89	342	
Type I Error		47	44	51	44		186

P. I. PFK

		GROUND DATA				Total Sample	Type II Error
		N	L	M	H		
INTERPRETER RESULTS	N	42	15	10	0	67	25
	L	23	29	8	9	71	42
	M	16	20	51	32	119	68
	H	1	8	28	48	85	37
Total Points		82	72	99	89	342	
Type I Error		40	43	48	41		172

P.I. HOT

		GROUND DATA				Total Sample	Type II Error
		N	L	M	H		
INTERPRETER RESULTS	N	32	6	2	1	41	9
	L	19	20	9	4	52	32
	M	22	36	45	19	122	77
	H	9	10	43	65	127	62
Total Points		82	72	99	89	342	
Type I Error		50	52	54	54		180

P.I. DTL

		GROUND DATA				Total Sample	Type II Error
		N	L	M	H		
INTERPRETER RESULTS	N	27	5	2	1	35	8
	L	30	29	10	3	72	43
	M	21	26	43	34	124	81
	H	4	12	44	51	111	60
Total Points		82	72	99	89	342	
Type I Error		55	43	56	38		182

Figure 4.7. The overall results for the four interpreters indicate that highly accurate identification of conifer density classes was not possible. (The number correct identifications are enclosed within the heavy lines along the diagonal of the boxes.) However, most of the errors occurred because the interpreter classified a particular point into a density class which was only one class above or below that which was considered ground "truth".

of timber would be much less than that associated with the misplacement of a line between non-forest land and forest land. The latter type of error would occur much less frequently because forest versus non-forest boundaries are usually well defined on the imagery.

In summary, it has been concluded from this series of tests that either the three-band electronic enhancement or the two-band color photographic composite would be best for classifying forest lands, rather than band no. 5 or the three-band color composite.

4.2.3.4 Evaluation of Variable-Date, Color Composite Transparencies

An experiment was conducted to determine the optimum ERTS-1 color composite image-date combination for identification of resource types within the Bucks Lake-Meadow Valley study area, which is located in the center of the Feather River watershed. The objective of the study was to evaluate several ERTS-1 color composite transparencies taken at different dates to determine the best image-date type useful in mapping both principal and comprehensive resource types. Four interpreters were assigned 133 test cells and 36 training cells, all randomly chosen on each of three ERTS-1 images. The images were (1) a July 26, 1972 color composite made from bands 4, 5 and 7 at NASA-Goddard, (2) an October 24, 1972 color composite made from bands 4, 5 and 7 at NASA-Goddard, and (3) an August 13, 1972 color composite made photographically from bands 5 and 7 at the CRSR.

An interpretation guide to the principal wildland resources within the Bucks Lake region (see Table 4.8) and an elevational zonation overlay aided the interpreters as they studied the training and test cells. Each ERTS-1 color composite was enlarged to a scale of 1:250,000 using the Simmon Omega variable condenser and projected onto a test sheet showing the location of each training and test cell.

Null hypotheses in conjunction with a two-way ANOV were used to test interpretation results for significant differences between interpreters and image types for eleven principal and five comprehensive resource types. Test results are presented in Tables 4.9 and 4.10.

Results of the experiment indicate that, on the basis of resource type, no significant differences exist between the means of percent correct and percent commission for both image types and interpreters. Hence, in all cases the null hypothesis: H_o : and i = 0 is accepted at the 0.1 level. For each resource type presented in Tables 4.9 and 4.10, the image types (X, Y, and Z), though confined to homogeneous groups, are ranked according to mean percent correct and mean percent commission errors. Although the achieving of a high level of identification accuracy for principal resource types was not an objective of this study, it is apparent from the results that standing water (X) was identified with high proficiency on all image types, and rangeland

TABLE 4.8. ERTS-1 IMAGERY INTERPRETATION GUIDE TO REGIONAL WILDLAND RESOURCES WITHIN THE FEATHER RIVER WATERSHED.

Resource Type Code	Resource Type	JULY 26, 1972 Characteristic Color Tone	AUGUST 13, 1972 Characteristic Color Tone	OCTOBER 24, 1972 Characteristic Color Tone	Training Cells	Occurrence
B	Dense mixed conifer	appears homogeneously dark; brownish red to dark red	dark purplish-grey to dark greenish-grey or medium dark greenish-purple	Dark purplish black or dark reddish black	235, 404	Extensive and homogeneously dark in appearance
BFK	Medium dense mixed conifer with hardwood and chaparral components	Medium reddish orange color tone; less saturated with slight pinkish-red tone	dark purplish-grey; medium purple; to medium purple-grey or strong purple	Dark strong purplish reddish grey to dark reddish brown or black	88, 131, 328, 341, 349, 362, 571, 593	Extensive type
VB	Sparse conifer with exposed terrain	light color tone due to exposed soil and rock; appears pinkish to greyish white pink	pale greenish-grey, pale green or pale greenish purple	Pale purplish grey to pale grayish red or red orange	13, 118, 635	Often on disturbed logged sites, exposed or poor sites
A	Fir forests	appears dark brownish-greyish red to dark red; extensive areas are "mottled" by deeply saturated red to red-orange riparian stringers & meadows	dark grey-purple to dark purple; medium greyish-purple to medium greenish-purple	Dark black to dark purplish black often with red-orange blotches or spots throughout extensive areas	67, 140, 245, 266, 517, 559	High elevations > 6,500 feet
F-FK	Hardwood dominated (often with chaparral)	strong red-orange or saturated orange pink; deep pinkish orange	pale to medium pinkish purple; pink purple to pale purplish green	Pale to medium reddish orange to bright strong homogeneous red-orange	89, 96, 434, 455	Occurs on southern exposures; often extensively homogeneous
K-KF	Dense homogeneous chaparral	medium pink to deep orange pink or red-orange	pale grey to greenish grey or medium green-purple or medium purple; pale purple	Deep saturated red to medium red-orange; sometimes black in shadow	46, 413, 539	Occurs on crests and exposed sites
VK-KV	Sparse chaparral cover on exposed terrain	pinkish to lighter pink color tone	pale-medium green, or grey-purple to greenish-grey. pale green	Pale purplish reddish gray or dark reddish gray to pale reddish orange or light tones	236, 298	Associated with exposed rock and soil
R	Mesic rangeland in interior valleys	very light pale pink or greyish white tone	pale green; pale green-grey	Strong red to medium pink or purple gray	487, 530	Occurs within interior valleys; not extensive
WU VU	Exposed ultrabasics rock and soil	light purplish grey to dark greyish tone	pale green to medium green-grey	Medium blue gray or purple blue-black	172, 193, 496	A distinct bedrock type with characteristically sparse vegetation; trends N and NW to S and SE
W, V	Exposed rock (granite included)	lighter tones, greyish pale white	very pale green or purple; pale green-grey to medium green	Medium to dark blue grey dark saturated grayish blue	299, 550	Exposed granite is light in tone and is sparsely vegetated
X	Standing waterbodies	dark blue black	dark black to dark blue-black	Very dark homogeneous blue black	223	Color tone homogeneous with distinct boundary

TABLE 4.9. ERTS-1 IMAGE-DATE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT* AND MEAN PERCENT COMMISSION ERROR** FROM IDENTIFICATIONS BY FOUR INTERPRETERS OF PRINCIPAL RESOURCE TYPES WITHIN THE BUCKS LAKE TEST SITE, FEATHER RIVER WATERSHED REGION.

RESOURCE TYPE	*** RANKED IMAGES	MEAN * PERCENT CORRECT	SIG. DIF. (0.1)	HOMO. GROUP (S)	*** RANKED IMAGES	MEAN ** PERCENT COMMISSION	SIG. DIF. (0.1)	HOMO. GROUP (S)
MIXED CONIFER (DENSE) B	Z X Y	62.5 48.0 41.5	NO	]	Y Z X	75.0 70.0 61.0	NO	]
MIXED CONIFER (MEDIUM DENSE) BFK	X Z Y	55.3 54.0 39.0	NO	]	Y Z X	54.0 49.3 43.8	NO	]
MIXED CONIFER (SPARSE) VB	X Z Y	30.8 28.8 27.0	NO	]	Y Z X	82.0 75.3 69.3	NO	]
FIR FOREST (DENSE) A	X Y Z	56.5 42.5 32.5	NO	]	Z X Y	46.8 35.5 33.8	NO	]
XERIC HARDWOODS F	Y Z X	55.0 45.0 40.0	NO	]	X Y Z	79.8 64.5 53.8	NO	]
MOUNTAIN CHAPARRAL (DENSE) K	Z X Y	22.3 19.5 9.3	NO	]	Y X Z	83.0 78.3 58.5	NO	]
MOUNTAIN CHAPARRAL (SPARSE) VK	X Z Y	28.3 16.0 15.8	NO	]	Y X Z	89.3 64.0 25.0	NO	]
RANGELAND R,N	X Z Y	87.5 50.0 50.0	NO	]	Y X Z	43.8 33.3 25.0	NO	]
ULTRABASIC ROCK WB, VB	X Z Y	31.3 31.3 25.0	NO	]	X Y Z	39.5 29.3 29.0	NO	]
EXPOSED ROCK AND SOIL W, V	X Z Y	31.3 31.3 25.0	NO	]	Y X Z	81.3 37.5 35.5	NO	]
STANDING WATER X	X Z Y	100.0 100.0 100.0	NO	]	X Y Z	16.5 0.0 0.0	NO	]

*Based on the number of the type present in the test sample.
**Based on the number of the type indicated by interpreter.
***Image X : July 26, 1972 ERTS-1 (4-5-7)
Y : August 13, 1972 ERTS-1 (5-7)
Z : October 24, 1972 ERTS-1 (4-5-7)

TABLE 4.10. ERTS-1 IMAGE-DATE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT* AND MEAN PERCENT COMMISSION ERROR**, FROM IDENTIFICATIONS BY FOUR INTERPRETERS OF COMPREHENSIVE RESOURCE TYPES WITHIN THE BUCKS LAKE TEST SITE, FEATHER RIVER WATERSHED REGION.

RESOURCE TYPE	*** RANKED IMAGES	MEAN * PERCENT CORRECT	SIG. DIF. (0.1)	HOMO. GROUP(S)	*** RANKED IMAGES	MEAN ** PERCENT COMMISSION	SIG. DIF. (0.1)	HOMO. GROUP(S)
COMMERCIAL CONIFER (A, B, BB)	Z Y X	91.0 84.0 80.0	NO	]	Y Z X	20.0 19.0 18.0	NO	]
CHAPARRAL-HARDWOOD ASSOCIATION COMPLEX (K, F, H)	X Y Z	50.0 45.0 44.0	NO	]	X Y Z	46.0 46.0 34.0	NO	]
INTERIOR GRASSLAND-RANGELAND (N, R)	X Y Z	87.0 50.0 50.0	NO	]	Y X Z	56.0 33.0 25.0	NO	]
EXPOSED ROCK AND SOIL (W, V)	X Z Y	62.0 58.0 49.0	NO	]	Y Z X	50.0 33.0 28.0	NO	]
STANDING WATER (X)	X Y Z	100.0 100.0 100.0	NO	]	X Y Z	0.0 0.0 0.0	NO	]

*Based on the number of the type in the test sample.
**Based on the number of the type indicated by the interpreter.
***Image X : July 26, 1972 ERTS-1 (4-5-7)
Image Y : August 13, 1972 ERTS-1 (5-7)
Image Z : October 24, 1972 ERTS-1 (4-5-7)

(R, N) was readily identifiable on the July 26 ERTS-1 image. In general, mean percent correct values for identification of principal resource types are low, with moderately high to high commission errors (see Table 4.10). However, test results expressed as comprehensive resource types (see Table 4.9) exhibit generally high levels of interpreter proficiency (high mean percent correct, low commission errors), especially for commercial conifer, interior grassland-rangeland, and standing water. Both the chaparral-hardwood association complex and exposed rock and soil types were marginally identifiable. Interpreter proficiency would improve however, with increased interpreter training, use of detailed keys, interpreter familiarity with the region, and supplemental aids. It should be noted that none of the interpreters used in this experiment was a skilled wildland photo analyst and two of the individuals were completely unskilled.

In summary, since the interpretation test results of this study have shown that no statistical differences exist (0.1 level) between the three image-date types for each resource category present, a "best" image-date type cannot be chosen.

4.2.3.5. Evaluations of ERTS-1 Imagery Interpretations Which Have Been Presented in Early Progress Reports

Numerous additional studies have been carried out within the Feather River watershed which were designed to test various components of the ERTS-1 system. A brief summary of several of these studies is given below.

The capabilities of the CRSR hardware and software systems were discussed in the September 30, 1972 Type I progress report. Briefly stated, the systems are now operating efficiently. ERTS-1 digital magnetic tape data can be displayed on a color television monitor and CALSCAN and RECLASS classification procedures can be applied. Examples of additive color displays of digital data appear in the September report. Likewise, preliminary results of attempting to classify vegetation/terrain types within the Bucks Lake study area using CALSCAN are shown in the January 31, 1973 Type 2 progress report. In the example just cited, three out of six types were reliably separated; these types were meadows, brush fields and barren areas. A much more detailed discussion of these automatic image classification and data processing techniques is present in section 4.2.4.2. of this chapter.

A study was completed for the Bucks Lake area in which forest classification results derived, using manual techniques, from three different sets of imagery were compared. The sets used were (1) 78 U.S. Forest Service 9 x 9 inch black-and-white, scale 1:15,840 photos, (2) three 9 x 9 inch false-color infrared, scale 1:120,000 photos and

(3) a small portion of one 8 x 10 inch ERTS-1 color composite print, enlarged to a scale of 1:125,000. Among the conclusions drawn from this study were (1) boundaries between contrasting forest types were properly mapped by photo interpretation on the ERTS-1 imagery, (2) subtle boundaries between less contrasting types (and, therefore, the less important boundaries) were the ones which were most often misplaced, and (3) the ERTS-1 imagery yielded less detailed information than the conventional aerial photographs, but the ERTS-1 photo interpreting was done much more cheaply (e.g., type delineations were drawn nearly 20 times faster on the ERTS-1 image than on black-and-white photographs, scale 1:15,840). A complete documentation of this study is given in the January 31, 1973 Type 2 progress report.

In another study, presented in the January 31, 1973 report, a manual interpretation test was performed on several ERTS-1 color composite images and also on a single band, no. 5, image. In no cases were interpretation results derived from one image type significantly different than from those derived from another for the three vegetation types identified (conifers, brush, and dry site hardwoods).

4.2.4 Evaluation of Practical Applications of ERTS-1 Imagery and Supporting Data

4.2.4.1 Case Study #1 -- Vegetation/Terrain Mapping Using Manual Analysis Techniques

Objectives

Nearly every land manager and resource specialist active within the Feather River watershed and contacted by our group expressed interest in obtaining regional statistics and maps on kind, amount and distribution of vegetation/terrain types occurring throughout the watershed. Moreover, it was generally understood among persons expressing this interest, that up-to-date vegetation/terrain information does not exist for this vast region because such information is nearly impossible to obtain using conventional mapping techniques. Several regional mapping projects, however, have been completed within the watershed, one done in 1967 by personnel of the California Department of Water Resources and another in 1970 by the California Comprehensive Framework Study Committee. Consequently, since the maps produced during these projects were available, an ideal opportunity presented itself whereby ERTS-1 imagery could be tested for purposes of mapping vegetation/terrain in terms of existing mapping objectives.

Attention, therefore, was focused onto a single project -- the California Comprehensive Framework Study Committee. Interviews were held with Committee participants to obtain detailed information about

the project. Specifically, information was gathered on mapping objectives, classification scheme used, mapping techniques used, personnel requirements, and estimated project costs. The vegetation/terrain type map presented in Figure 4.8 illustrates the Feather River watershed; it is part of the Sacramento Subregion map which was prepared by the Framework Study Committee.

Thus, the objectives in our study were (1) to map with ERTS-1 imagery the resource complex within the entire Feather River watershed using the generalized Framework Study mapping objectives as a guide, (2) to determine the level of accuracy associated with the generalized map made from ERTS-1 by comparing it with the map made from high altitude false-color infrared photography, (3) to determine the level of accuracy associated with the Framework Study map by comparing it with the map made from high altitude photography, (4) to map with ERTS-1 imagery the resource complex within the entire Feather River watershed, using detailed mapping objectives set at seeking the maximum amount of information about the region, (5) to determine the level of accuracy associated with the detailed map made from ERTS-1 imagery by comparing it with the map made from high altitude photography, and (6) to determine the timing and cost factors associated with preparing the generalized and the detailed maps made from the ERTS-1 imagery.

ERTS-1 Map Using Generalized (Framework Study) Classification Scheme

Regional mapping of the entire Feather River watershed from ERTS-1 color composites (bands 4-5-7) was done utilizing three dates of imagery in combination. The dates were July 26, 1972, August 13, 1972 and October 24, 1972. The August image was a precision processed image; thus, it provided an undistorted map base necessary for accurately locating highly identifiable resources such as lakes and rangeland areas. A regional vegetation/terrain type map was produced by projecting and enlarging the ERTS-1 color composite transparencies to a scale of 1:250,000. The interpreter frequently interchanged the July and October images to take advantage of seasonal changes in reflectance occurring within certain vegetation types. The first map produced using this technique was made following the generalized classification scheme defined in the California Framework Study. The final ERTS-1 map product is illustrated in Figure 4.9.

Accuracy of Generalized Map

An evaluation of the level of accuracy associated with the generalized ERTS-1 map shown in Figure 4.9 is presented in Figure 4.10. The evaluation was done by comparing the ERTS-1 map with the map made from high flight photography (see Figure 4.2). A grid of 474 points was constructed and placed over each of the maps with identical alignment. Thus the vegetation/terrain types within which the various points fell on each map were determined and tallied. The tallied results were

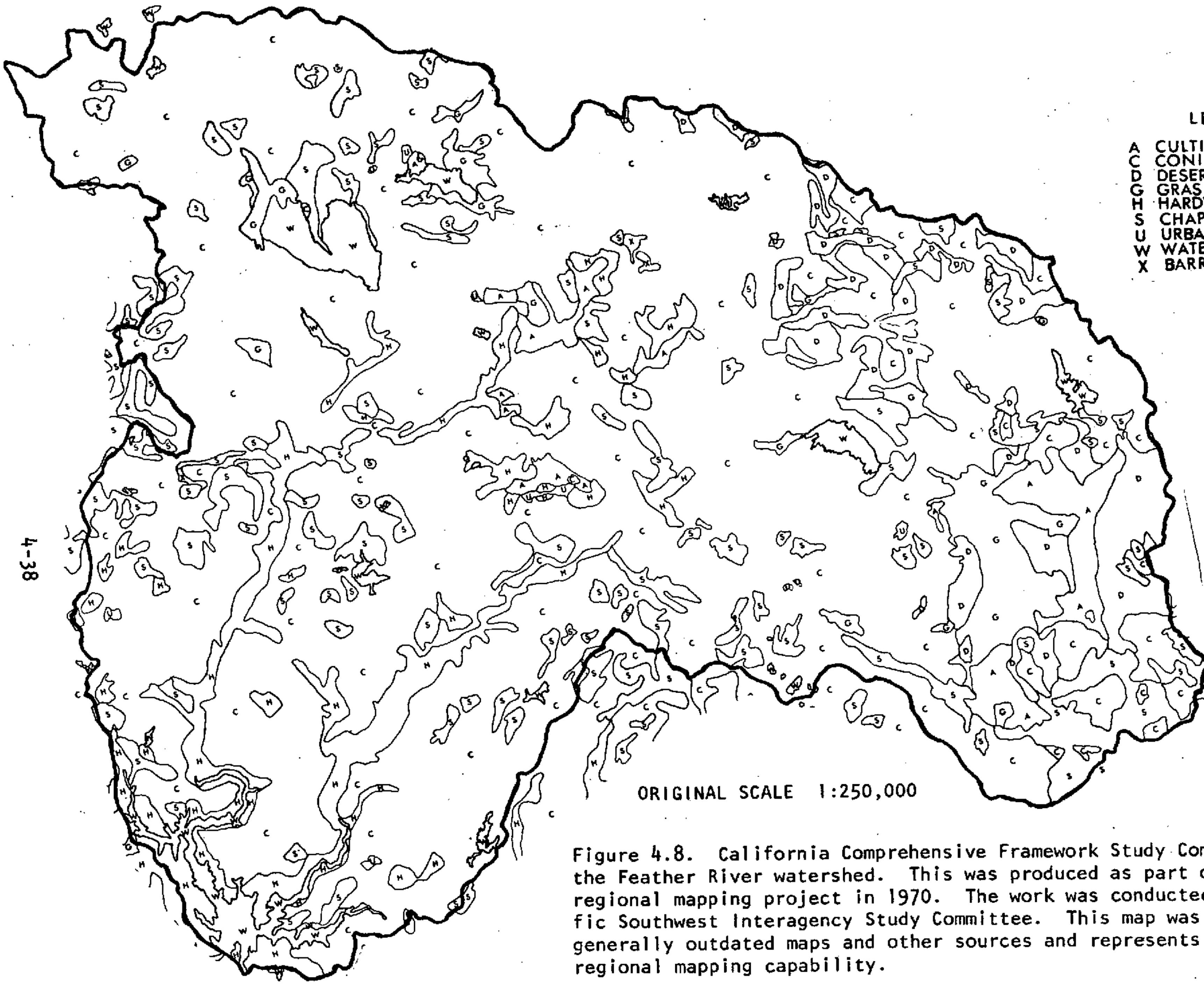


Figure 4.8. California Comprehensive Framework Study Committee map of the Feather River watershed. This was produced as part of a statewide regional mapping project in 1970. The work was conducted by the Pacific Southwest Interagency Study Committee. This map was made from generally outdated maps and other sources and represents pre-ERTS regional mapping capability.

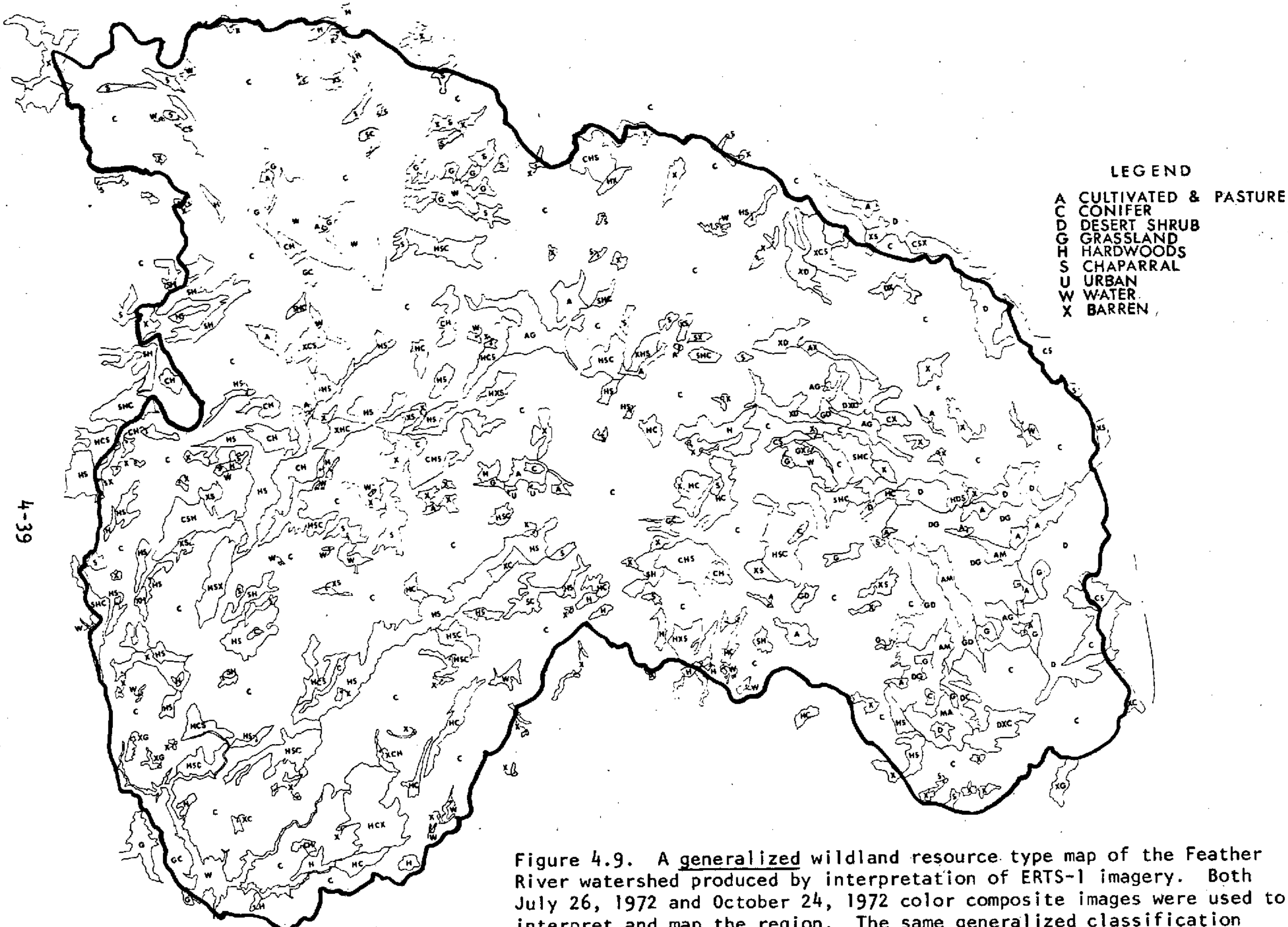


Figure 4.9. A generalized wildland resource type map of the Feather River watershed produced by interpretation of ERTS-1 imagery. Both July 26, 1972 and October 24, 1972 color composite images were used to interpret and map the region. The same generalized classification scheme used during the California Comprehensive Framework Study project (see Figure 4.8) was used when making this map.

HIGH ALTITUDE GROUND COMPARATIVE MAP DATA — INCLUSIVE RESOURCE TYPES	TOTAL PRESENT	TOTAL OMITTED	COMPREHENSIVE RESOURCES TYPE MAP FROM ERTS-1 IMAGERY: CONIFER (C)	CHAPARRAL (S)	HARDWOOD (H)	GRASSLAND (G)	CULTIVATED & PASTURE (A)	DESERT SHRUB (D)	BARREN (X)	WATER (W)	URBAN (U)	PERCENT OMISSION*	PERCENT CORRECT*
CONIFER (A, B, BB, C, E)	294	7	287	1	4	1			1			3	97
CHAPARRAL (K, J)	41	27	15	14	10		1		1			66	34
HARDWOOD (F, H, I)	37	7	5	2	30							19	81
GRASSLAND (G, S, R, N)	15	4	2		1	11		1				27	73
CULTIVATED & PASTURE (P, Q, R, M)	20	2	1				18	1				10	90
DESERT SHRUB (L, S)	19	1						18	1			5	95
BARREN (T, U, W, V)	34	14	10		1	1		2	20			41	59
WATER (X)	13	0								13		0	100
URBAN (U)	1	0									1	0	100
TOTALS	474	62							AVERAGE				81
TOTAL INDICATED**			320	17	46	13	19	22	23	13	1	474	
TOTAL COMMITTED			33	3	16	2	1	4	3	0	0	62	
PERCENT COMMISSION*			11	7	43	13	5	21	9	0	0		
PERCENT COMMISSION**			10	18	35	15	5	18	13	0	0		

*Based on the total number within the sample.
**Based on the total number indicated by the interpreter results

Figure 4.10. An evaluation of the ERTS-1 generalized resource type map (see Figure 4.9) is presented in the above table. Comparisons of the ERTS-1 map with the high flight map (see Figure 4.2) indicate excellent agreement. The percent correct results for the identification and mapping of conifer, hardwood, grassland, cultivated and pasture, desert shrub, water and urban types indicate high interpreter proficiency. Commission errors are low except for hardwood types. High omission errors for the chaparral type are associated with the frequent misinterpretation of chaparral as a hardwood or conifer type.

summarized and are shown in Figure 4.10. These results indicate overall excellent agreement. Specifically, the average percent correct, (assuming that the high flight map is "correct"), was 81 percent. The interpreter was able to proficiently map conifer forest, hardwood forest, grasslands, cultivated and pasture lands, desert shrub lands, water bodies and urban lands. The types that were most difficult to map were chaparral lands and barren lands.

Accuracy of Framework Study Map

A similar point-by-point evaluation was made of the Framework Study Map shown in Figure 4.8 by comparing it with the high flight map. The tabulated results are illustrated in Figure 4.11 and show good overall agreement in that the average percent "correct" was 68 percent. Specifically, good agreement exists for conifer forest, grasslands, cultivated and pasture lands, desert shrub lands, water bodies and urban lands. However, poor agreement exists for chaparral lands, hardwood forest, and barren lands.

ERTS-1 Map Using Detailed Classification Scheme

Regional mapping was done of the entire Feather River watershed from ERTS-1 color composites (July 26, 1972, August 13, 1972 and October 24, 1972) with an objective of mapping vegetation/terrain types in maximum detail. The techniques used by the interpreter were similar to those used when preparing the generalized ERTS-1 map; however, a much more detailed classification scheme was employed in this case. Figure 4.12 illustrates the classification scheme used and the final map product derived from ERTS-1 imagery.

Accuracy of Detailed ERTS-1 Map

A point-by-point evaluation was made of the detailed ERTS-1 map shown in Figure 4.12 by comparing it with the high flight map. The summary results for 474 points are given in Figure 4.13. Note that the overall agreement between the two maps might still be called "good", (i.e., the average percent "correct" was 66 percent).

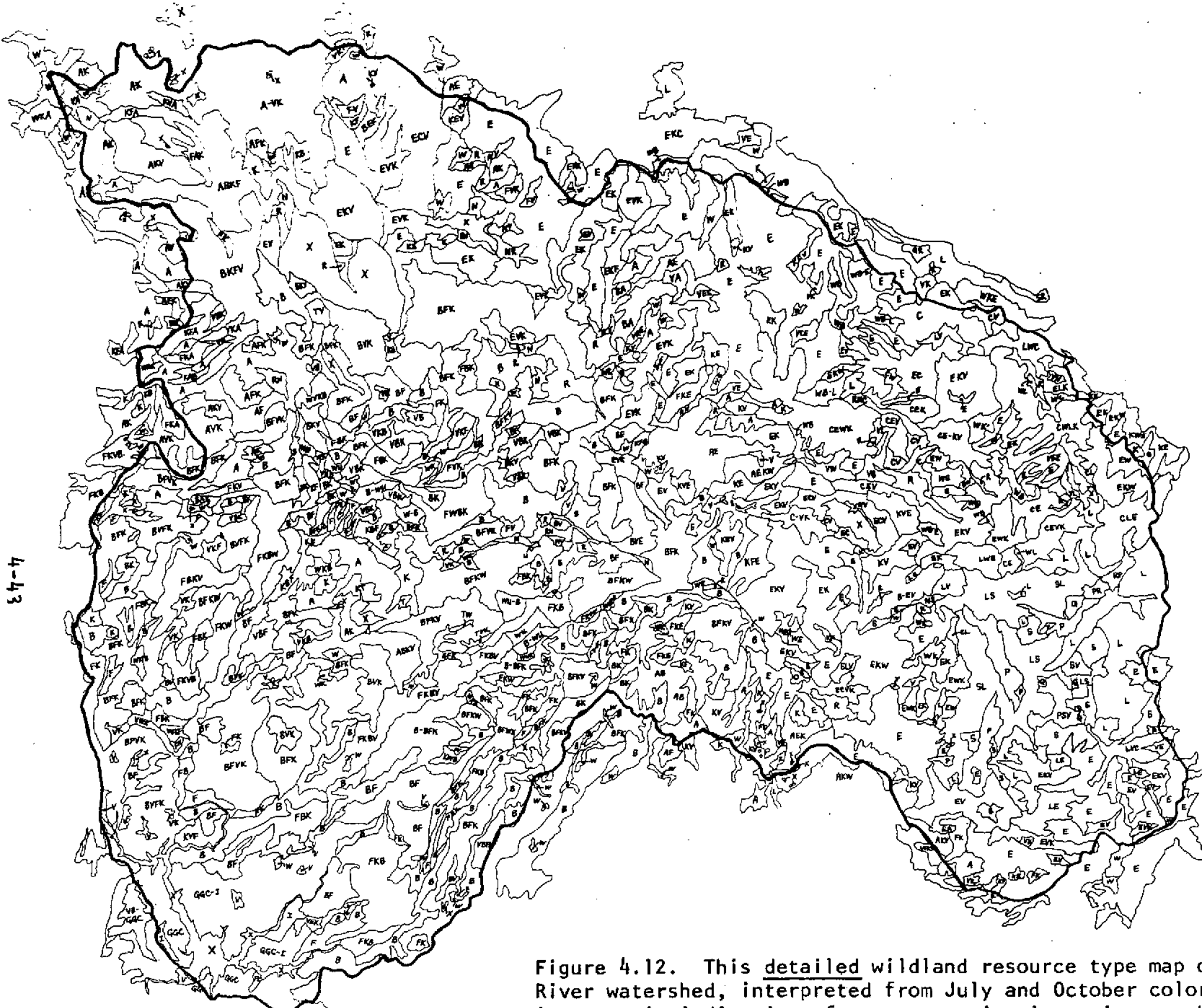
The results in Figure 4.13 indicate very high interpreter proficiency for identifying and mapping the eastside timberland-chaparral complex, eastside sagebrush scrub, forest plantation, urban-residential, and water resource types. Both the forest plantation and urban types, however, represent tenuous data, since the total number of points present in each sample was small.

The high omission errors shown in Figure 4.13 are attributable to the relative scarcity of certain resource types. Moderately high proficiency was demonstrated in identifying and mapping fir forests, mixed conifer, hardwoods, pine-oak woodland, xeric grassland, grassland

HIGH ALTITUDE GROUND COMPARATIVE MAP DATA	COMPREHENSIVE FRAMEWORK STUDY COMMITTEE MAP BASE												
INCLUSIVE RESOURCE TYPES	TOTAL PRESENT	TOTAL OMITTED	CONIFER (C)	CHAPARRAL (S)	HARDWOOD (H)	GRASSLAND (G)	CULTIVATED & PASTURE (A)	DESERT SHRUB (D)	BARREN (X)	WATER (W)	URBAN (U)	PERCENT OMISSION*	PERCENT CORRECT*
CONIFER (A, B, BB, C, E)	293	5	288	2	3							2	90
CHAPARRAL (K, J)	49	18	10	31	8							37	63
HARDWOOD (P, H, I)	33	14	9	5	19							42	58
GRASSLAND (G, S, R, N)	22	7	2	2		15	2	1				32	68
CULTIVATED & PASTURE (P, Q, R, M)	15	4				4	11					27	73
DESERT SHRUB (L, S)	23	7				7		16				30	70
BARREN (T, U, W, V)	21	21	12	3	3			3	0			100	0
WATER (X)	17	1		1						16		6	94
URBAN (U)	1	0									1	0	100
TOTALS	474	77							AVERAGE				68
TOTAL INDICATED**			321	44	33	26	13	20	0	16	1	474	
TOTAL COMMITTED			33	13	14	11	2	4	0	0	0	77	
PERCENT COMMISSION*			11	27	42	50	13	17	0	0	0		
PERCENT COMMISSION**			10	29	42	42	15	20	0	0	0		

*Based on the total number within the sample.
**Based on the total number indicated by the interpreter results

Figure 4.11. An evaluation of the Comprehensive Framework Study Committee Map Base (see Figure 4.8) is presented in the above table. Comparisons of the Framework Study map with the high flight map (see Figure 4.2) indicate good agreement. The percent correct results for identification and mapping conifer, cultivated pasture, desert shrub, water, and urban resources indicate high interpreter proficiency. Commission errors are generally low except for hardwood and grassland types.



RESOURCE TYPE

A,O	FIR FOREST - MESIC MEADOW
B,BB	INTERMEDIATE MOUNTAIN MIXED CONIFER
C	EASTSIDE PINE - SCRUB FOREST
E	EASTSIDE TIMBERLAND CHAPARRAL COMPLEX
F	INTERMEDIATE MOUNTAIN XERIC HARDWOODS
GGC	WESTSIDE FOOTHILL PINE-OAK WOODLAND - GRASS
I	WESTSIDE FOOTHILL MIXED HARDWOOD-CONIFER FOREST
J	WESTSIDE VALLEY FRONT CHAPARRAL
K	INTERMEDIATE MOUNTAIN CHAPARRAL
L	EASTSIDE VALLEY AND BASIN FRONT SAGEBRUSH SCRUB
N	INTERIOR VALLEY XERIC GRASSLAND
Q,R	CULTIVATED CROPLANDS AND MESIC RANGELAND
P	FRESHWATER MARSHLAND
S	XERIC EASTSIDE GRASSLAND-SCRUB RANGELAND
T	FOREST PLANTATION SITES
U	URBAN-RESIDENTIAL
V,W	EXPOSED SOIL AND ROCK (WG, WA, WP)
WB	EXPOSED BASALT BARRENS
WU	EXPOSED ULTRABASIC ROCK
X	STANDING WATER

Figure 4.12. This detailed wildland resource type map of the Feather River watershed, interpreted from July and October color composite ERTS-1 imagery, is indicative of present regional mapping capability from satellite imagery. The interpretation work was performed independently of other source information by a highly-skilled photo analyst.

HIGH ALTITUDE COMPARATIVE MAP DATA — RESOURCE TYPE	TOTAL PRESENT	TOTAL OMITTED	FIR FORESTS	MIXED CONIFER	EASTSIDE PINE-SCRUB	EASTSIDE TIMBERLAND-CHAPARRAL	XERIC HARDWOODS	PINE-OAK WOODLAND GRASS-CHAPARRAL	FOOTHILL MIXED HARDWOOD-CONIFER	FOOTHILL CHAPARRAL	MOUNTAIN CHAPARRAL	EASTSIDE SAGEBRUSH SCRUB	XERIC GRASSLAND	MARSHLAND	CULTIVATED CROPLANDS	MESIC RANGELAND	GRASSLAND SCRUB-RANGELAND	FOREST PLANTATION	URBAN-RESIDENTIAL	EXPOSED SOIL-ROCK	STANDING WATER	% OMISSION	% CORRECT*
			PRINCIPAL RESOURCE TYPE MAP FROM ERTS-1																				
FIR FORESTS	72	25	47	19		5	1															34	65
MIXED CONIFER	129	28	8	101		15	3				1									1		21	78
EASTSIDE PINE-SCRUB	12	4			8	3														1		33	66
EASTSIDE TIMBERLAND-CHAPARRAL	80	7	3		2	73					1									1		9	91
XERIC HARDWOODS	26	4		4			22															15	84
PINE-OAK WOODLAND GRASS-CHAPARRAL	8	2		1				6	1													25	75
FOOTHILL MIXED HARDWOOD-CONIFER	3	3		2				1	0													100	0
FOOTHILL CHAPARRAL	4	2		2						2												50	50
MOUNTAIN CHAPARRAL	28	18	1	4	2	5	6				10											64	35
EASTSIDE SAGEBRUSH SCRUB	13	0										13										0	100
XERIC GRASSLAND	8	3				1							5				2					37	62
MARSHLAND	2	1												1		1						50	50
CULTIVATED CROPLANDS	0	0													0							0	0
MESIC RANGELAND	14	6				1					1	1		3		8						42	57
GRASSLAND SCRUB-RANGELAND	16	4										4					12					25	75
FOREST PLANTATION	4	0																4				0	100
URBAN-RESIDENTIAL	1	0																	1			0	100
EXPOSED SOIL-ROCK	43	13		1	6	2	2	1			1									30		30	69
STANDING WATER	11	0																			11	0	100
TOTALS	474	120																				AVERAGE	66
TOTAL INDICATED			59	134	18	105	34	8	1	2	14	18	5	4	0	9	14	4	1	33	11	474	
TOTAL COMMITTED			12	33	10	32	12	2	1	0	4	5	0	3	0	1	2	0	0	3	0	120	
% COMMISSION*			17	26	83	40	46	25	33	0	14	38	0	150	0	7	12	0	0	6	0		
% COMMISSION**			20	25	55	30	35	25	100	0	28	27	0	75	0	11	14	0	0	9	0		

* BASED ON THE TOTAL NUMBER WITHIN THE SAMPLE

** BASED ON THE TOTAL NUMBER INDICATED BY THE INTERPRETER

Figure 4.13. Comparative data expressed as percent omission errors, percent commission errors, and percent correct are presented in this figure between the principal resource type map interpreted from ERTS-1 imagery and the high altitude map base. These results, based on 474 data points, distributed among nineteen principal resource types, indicate moderate to high interpreter proficiency in the identification of most types present. A complete discussion of these results appears in the text.

scrub rangeland, and exposed soil and rock. Commission errors were high for eastside pine scrub and marshland, indicating interpreter difficulty in identifying these types.

Timing and Cost Factors Associated with Preparing the Generalized and Detailed ERTS-1 Maps

Actual time and cost figures associated with producing the high flight map (see Figure 4.2), the generalized ERTS-1 map (see Figure 4.10) and the detailed ERTS-1 map (see Figure 4.12) are presented in Table 4.11. The most time-consuming phase of interpretation is the classification of wildlands from the imagery. The total time required to map the entire Feather River watershed varied from 11.5 hours for generalized mapping, and 17.5 hours for detailed mapping from the ERTS-1 imagery, to 182.0 hours for mapping from the high flight photos. Costs associated with these time figures are also presented in Table 4.11. These figures demonstrate cost ratios of 16:1 and 10:1, respectively, between high flight and ERTS-1, depending on the level of mapping detail required from the ERTS-1 images.

Conclusions

The Case Study presented above was designed to determine the practical usefulness of ERTS-1 imagery for vegetation/terrain mapping over vast, inaccesible wildland areas. The study has shown that ERTS-1 imagery is ideal for making generalized vegetation/terrain type maps, similar to the one made by the California Comprehensive Framework Study Committee. Specifically, the ERTS-1 map made for the entire 2-1/4 million acre Feather River watershed required only 11.5 hours of interpretation time. When the entire watershed was mapped in maximum detail with ERTS-1 imagery, the interpretation time required was 17.5 hours. To map the same area with high flight photos would cost at least ten times or sixteen times more, respectively, than with ERTS-1 imagery; however, a much greater amount of information would be derivable from the high flight photos. In addition, the generalized ERTS-1 map was certainly as good as, if not slightly better than, the Framework Study map in terms of level of accuracy.

The total estimated cost associated with preparing the Framework Study maps for the entire state of California (105 million acres) was approximately $12,000. This figure reflects only the man-hours associated with the task and does not include such items as supplies, travel expenses, overhead, etc. A similar projected cost for the making of a generalized vegetation/terrain type map for the entire state of California with the aid of ERTS-1 imagery would be approximately $4,000. Consequently, not only can a more timely and more accurate regional vegetation/terrain map be prepared from ERTS-1 imagery than from using conventional methods (i.e., Framework Study), but also the ERTS-1 map

TABLE 4.11. ACTUAL INTERPRETATION TIME AND COSTS ASSOCIATED WITH MAPPING VEGETATION/TERRAIN TYPES WITHIN THE FEATHER RIVER WATERSHED.

	MAPPING FROM HIGH-ALTITUDE AIRCRAFT FALSE-COLOR INFRARED PHOTOS	MAPPING (GENERALIZED) FROM ERTS-1 COLOR COMPOSITE IMAGERY	MAPPING (DETAILED) FROM ERTS-1 COLOR COMPOSITE IMAGERY
DELINEATION OF WATERSHED BOUNDARY	3.0 HOURS	0.5 HOURS	0.5 HOURS
PLOTTING EFFECTIVE AREAS	5.0	0.0 HOURS	0.0 HOURS
DELINEATION OF HOMOGENEOUS AREAS	48.0 HOURS	2.0 HOURS	4.0 HOURS
PHOTO INTERPRETATION TRAINING	6.0 HOURS	6.0 HOURS	6.0 HOURS
RESOURCE TYPE CLASSIFICATION	120.0 HOURS	3.0 HOURS	7.0 HOURS
TOTAL INTERPRETATION TIME REQUIRED	182.0 HOURS	11.5 HOURS	17.5 HOURS
HOURLY WAGE	$7.00/HOUR	$7.00/HOUR	$7.00/HOUR
TOTAL INTERPRETATION COSTS (TIME)	$1274.00	$80.50	$122.50
TOTAL COST/ACRE	0.0566 ¢	0.00357 ¢	0.00544¢
COST RATIO	16	1	1
	10		

can be prepared for approximately <u>one-third</u> the cost.

4.2.4.2. <u>Case Study #2 -- A Timber Inventory Based on Manual and Automated Analyses of ERTS-1 and Supporting Aircraft Data Using Multistage Probability Sampling</u>

In order to test the usefulness of ERTS-1 imagery for wildland resource inventories, a timber inventory was performed in which the ERTS-1 imagery acted as the first stage of a multistage sampling design. The objective of the inventory was to estimate the standing volume of merchantable timber within the Quincy Ranger District (215,000 acres) of the Plumas National Forest in California. Secondary objectives of the inventory were: (1) to test the operational efficiency of the sampling procedures of the multistage sample design, (2) to test the effectiveness of the CALSCAN* classifier on the ERTS-1 data, (3) to determine the value of ERTS-1 data and aircraft data in reducing the sampling error, and (4) to compare the costs of this timber inventory with those for an equivalent inventory using conventional procedures.

A three-stage sampling design was tested in which "timber volume" was the variable estimated. At each stage timber volume estimates were made from sampling units whose probabilities of selection in the sample were proportional to the corresponding predicted volumes, as interpreted from the next smaller scale imagery. Timber volume estimates were made from three stages: (1) the first stage involved automatic classification of the timberland on the ERTS-1 data tapes into four timber volume classes. Within the classified area, subsamples were selected (called primary sampling units; PSU) from which a more refined estimate of timber volume could be made in the second stage; (2) the second stage involved the acquisition of low altitude photography of selected primary sampling units to select photo plots on which to make a second timber estimate by comparison with photo-volume tables; (3) the third stage involved selecting individual trees within selected sample photo plots by photo measurement of all merchantable trees. Selected trees were then precisely measured (for volume) on the ground and these volume measurements in turn were expanded through the various stages of the sample design to estimate total timber volume over the national forest land with the Quincy Ranger District.

The statistical procedures for expanding the timber volume estimates though the various stages of the timber inventory are discussed in an appendix to this study. The procedures for selecting sampling sites and estimating timber volumes from ERTS-1 and aircraft imagery at each of the stages of the sample design are described in subsequent sections in order to demonstrate how the ERTS and supporting

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* The CALSCAN system is described in Chapter 2 of this report and the accuracy test of the classifier is discussed in an appendix to this section.

aircraft data were necessary components in performing the timber inventory.

Stage 1. CALSCAN Classification of ERTS-1 Data and Primary Sample Unit Selection

ERTS-1 data tapes of the Quincy Range District, Plumas National Forest, were classified on the CRSR interactive human-computer system using a CALSCAN point-by-point classification routine. The coordinates of the Ranger District boundary and those of non-national forest land within the District were identified on the tapes so that only those picture elements associated with national forest land were classified and incorporated into the inventory. This procedure considerably reduced the costs of classification.

Classification was based on four timber volume classes, namely (1) non-forest; (2) forest sites containing less than 10,000 board feet per acre (bd ft/ac); (3) forest sites containing 10,000 to 20,000 bd ft/ac, and (4) forest sites containing more than 20,000 bd ft/ac. The classifier was trained to recognize each of the four timber volume classes based upon photo interpreter selection of 33 training cells whose estimated range of timber volumes was based on photo interpretations of crown closure and average crown diameter. The training cells were selected from interpretation of high altitude color infrared photography (scale 1:120,000). Each of the training cells was located and digitized on the ERTS imagery. Point-by-point classification of all ERTS data points within the Quincy Ranger District proceeded by matching each data point (picture element) with the corresponding training cell. The results were grouped into the four timber volume classes. The accuracy achieved by automatic classification of ERTS tapes lends credence to the efficiency which can be gained in the timber inventory through analysis of ERTS data tapes in the initial stages of the sample design. (The results of the accuracy test of the classifier appear in Appendix I.)

The classified ERTS data (CALSCAN classification) of the Quincy Ranger District (see Figure 4.14) were divided into rectangular sampling units (called primary sampling units). Each unit measured 1,325 feet wide by 1-1/2 miles long (see Figure 4.15). The size of these sampling units was based upon (1) a practical area which could be photographed in a single flight line by a light aircraft using a 35 mm camera system, (2) the ability of the ground crew to complete the ground work for a flight line in one day and (3) the variation between SU's.

For each primary sampling unit, the following information was computed:

1. The number of points in each volume class (within the unit).

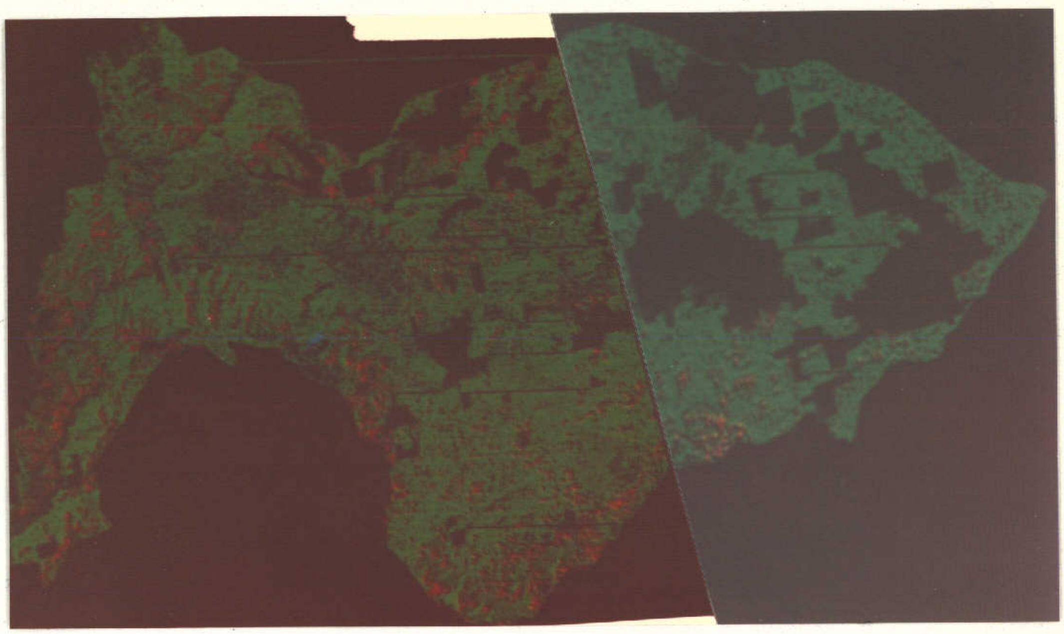


Figure 4.14. The above image, taken from a color CRT, shows the west half and the east half of the Quincy Ranger District in terms of CALSCAN classification. The dark areas are non-forest lands, the orange areas are brush, and the green areas are timberlands.

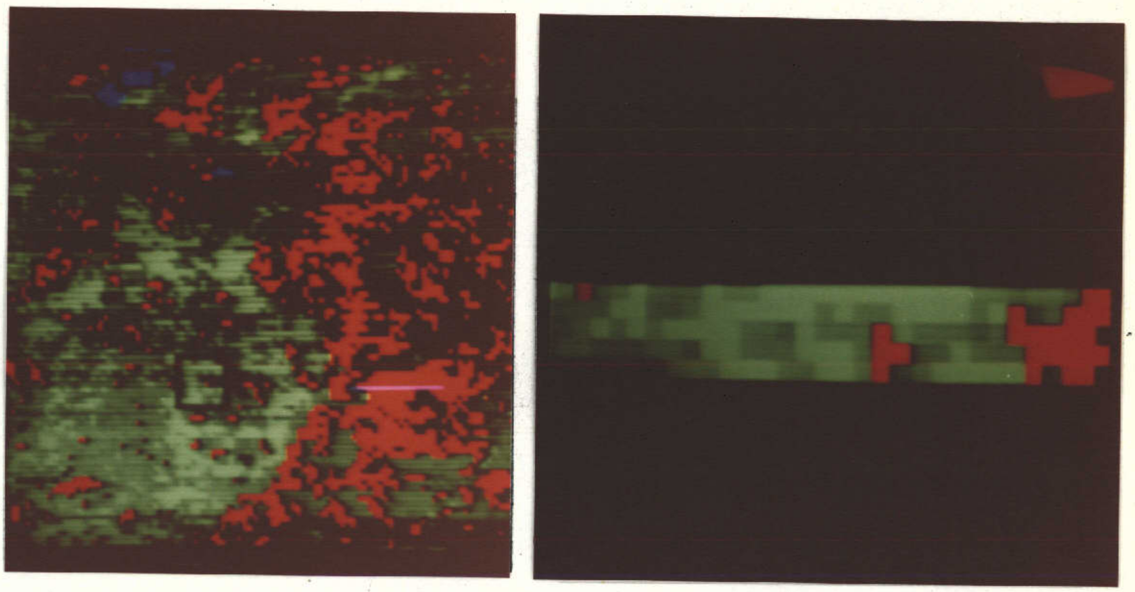


Figure 4.15. The photo on the left shows a CALSCAN area around the P.S.U. as seen in the photo on the right. When looking at the blow-up of the P.S.U., the different levels of green become apparent. The light green is estimated at 20,000 and above bd ft/ac, the medium green is 10,000-20,000 bd ft/ac, and the darkest green is 0-10,000 bd ft/ac. The orange is brush.

2. The weighted total volume for each volume class*

3. The sum of the weighted totals for all classes

4. A cumulative sum of the weighted totals

5. The mean volume for the sampling units

6. The variance of the sampling units

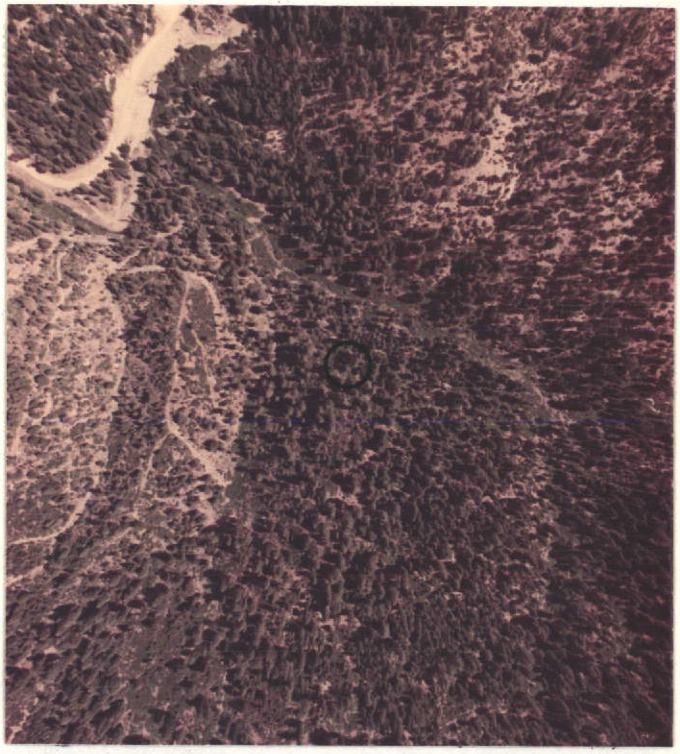
Based upon the information either estimated or computed for each primary sampling unit, four units were selected for further sampling in the timber inventory. (Appendix II explains why only four sampling units were required.) The four units were selected with probability of selection proportional to their estimated volumes. The locations of the four selected PS units were transferred from the ERTS classified images to the color-infrared high altitude aerial photography (scale 1:120,000), to facilitate locating them accurately from the air when they were photographed from a lower altitude as part of the second stage of the timber inventory.

Stage II. Volume Estimation on Low Altitude Photography

Two 35 mm cameras were used to obtain low altitude photography of the selected primary sampling units simultaneously at two different scales (see Figure 4.16). A 24 mm focal length, wide angle lens was used to acquire complete coverage of each sampling unit at an approximate scale of 1:7,500, and a 200 mm focal length was used to obtain large scale stereo triplets, scale approximately 1:1,000, from which to make precise photo estimates of timber volume. The camera with the telephoto lens was equipped with a motorized film drive which enabled each stero triplet to be taken within one second at five second intervals while the camera with the wide lens was operated manually to obtain single frames at five second intervals. The photo coverage for each PSU consisted of ten stereo triplets and ten wide angle photographs (see Figure 4.16).

The wide-angle photos of each primary sampling unit were mosaicked together to show its full area. The center of the middle photo for each stereo triplet was used as the plot center, and these were located and marked on the mosaic. The plot centers were also located on a topographic map and the elevation of each was determined.

* The weighted total volume was determined by multiplying the number of points in each volume class by the assigned weight for that class. The assigned weight is the volume estimate given by PI's. In this instance T1 (0-10,000 bd ft/ac) = 1, T2 (10,000-20,000 bd ft/ac) = 2, T3 (20,000 bd ft/ac and above) = 3, and all non-forest types were given a weight = 0.



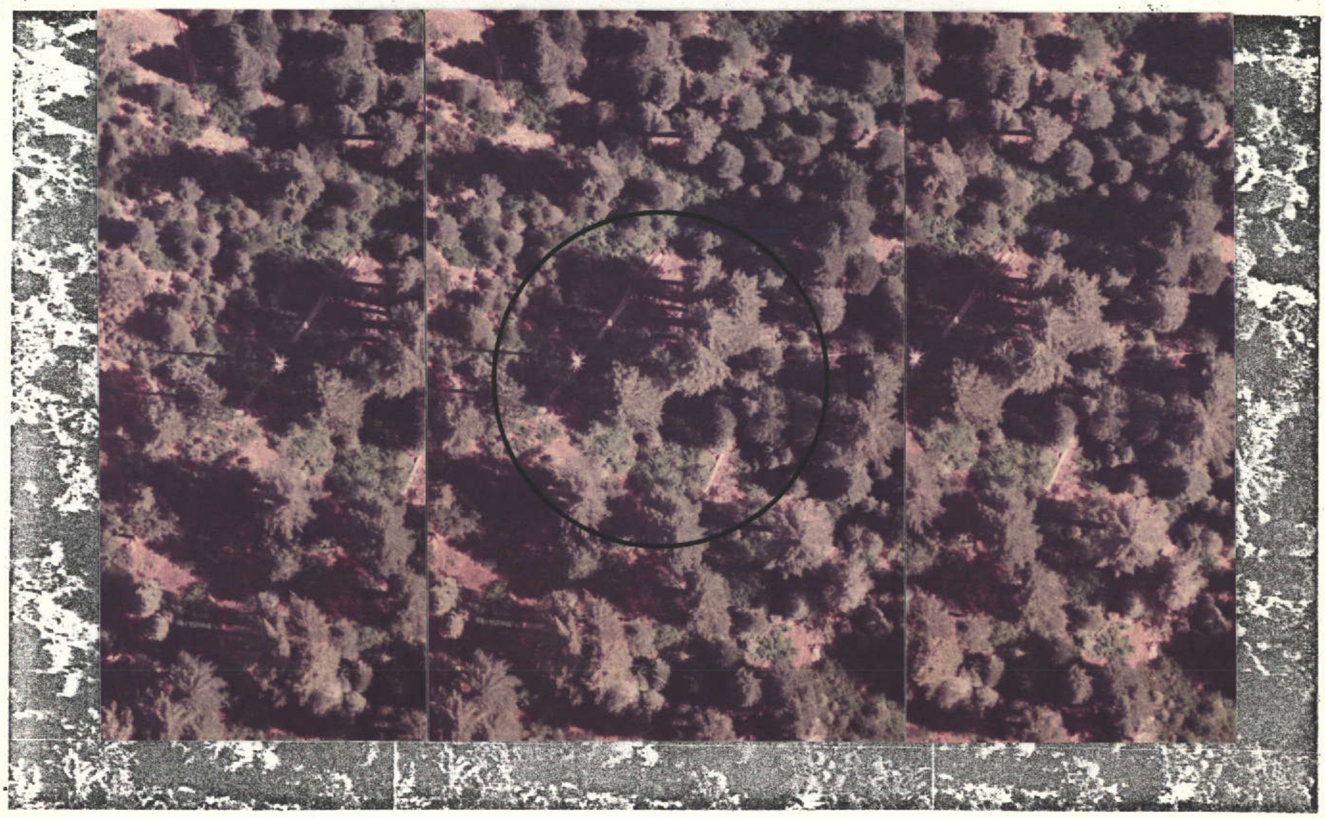


Figure 4.16. The top photo was taken with a 24 mm lens and the bottom photos illustrate the stereo triplet obtained by the telephoto lens at the same time. The inked circle on the bottom center photo delineates the scale-adjusted, 0.4 acre ground plot.

The scale of each photo plot was determined, and a 0.4-acre circular plot was drawn about the photo plot center. The timber volume in each 0.4-acre photo plot was estimated by referring to photo-volume tables based upon interpretation of percent crown closure and measurement of average stand height using a parallax bar (Chapman, 1965)*. Within each primary sampling unit two out of the ten possible photo plots were chosen with probability of selection proportional to their estimated volumes.

Stage III. Selection of Trees for Precise

Ground Measurement of Timber Volume

In the third stage, all trees of merchantable size within each selected photo plot were pin-pricked and numbered. For each of these trees, the average crown diameter was determined based on the longest and shortest dimensions of their crowns. After adjustments for scale, the average crown diameter value was cubed (raised to the third power) to be used as a relative measure of the merchantable volume of wood in the individual tree for the third stage volume estimation. Four trees were selected from the population of merchantable trees found within each photo plot, to be measured by a dendrometer on the ground. (Selection again was based upon probability proportional to the estimated volume of each tree).

A two-man crew went into the Quincy Ranger District with a Barr and Stroud optical dendrometer to measure the selected trees (see Figure 4.17). The large scale (low altitude) photographs were used to locate the photo plot centers as well as the trees within the plots to be measured. In addition to the dendrometer measurements, an easily recognizable feature on the ground near the plot center was measured in order to get a more accurate estimation of the photo scale of the plot. The dendrometer measurements were brought back from the Quincy Ranger District and entered into a computer program that calculated merchantable stem volumes for the individual trees. These volumes were then expanded through each stage of the sample design to estimate total volume on the District, consistent with the statistical methods for variable probability sampling (see Appendix II to this section).

Results

The total volume of timber on the Quincy Ranger District of the Plumas National Forest was estimated to be 407 million cubic feet (approximately 2.44 billion board feet) based on eight selected photo plots located within four primary sampling units. The sampling error associated with this estimate was 8.2 percent, which falls well below the acceptable S.E. of 20 percent for the District. This indicates

* Chapman, Roger C. 1965. Preliminary Aerial Photo Stand-Volume Tables for Some California Timber Types. Pacific Southwest Forest and Range Experiment Station Research Paper No. 93. 9 pp.

Figure 4.17. The photo on the left shows the Barr and Stroud optical dendrometer in use. The photo on the right shows the tree diameter being measured with diameter-tape.

that the true volume of merchantable trees on the Quincy District will fall into the interval 352-462 million cubic feet with .80 probability.

There were only thirty-one trees total measured by an optical dendrometer on the ground at the eight plots (thirty-two trees should have been measured but one plot out of the eight contained only three merchantable trees which could be measured). The field work required one week's time by a two-man crew, and the total area of the ground plots measured was 3.2 acres, representing a sampling fraction of about 1/67,000.

Table 4.12 lists the costs of a timber inventory on 215,000 acres using the multistage sampling design, just as described, as an operational system. The expected costs of making such an inventory on the Plumas National Forest, which has an area of 1,161,554 acres, would be approximately $15,000 and would take five months to complete. In contrast, the U.S. Forest Service recently made an inventory on the Plumas National Forest at a total cost of $300,000 and took two years to complete it.

Conclusions

The preliminary results of the timber inventory of the Quincy Ranger District indicate that the procedures employed in the multistage sampling design are valid and substantially reduce both the costs and the amount of time required to perform a timber inventory of acceptable accuracy for a large area. This study demonstrates the value of ERTS-1 data for accurately correlating picture elements with timber volume estimates as a fundamental first step in selecting primary sampling units in the first stage of the inventory. The inventory procedures utilized here will be applied for the remaining districts of the Plumas National Forest in an effort to estimate the total timber volume on the forest. Based on the preliminary results it is felt that the sampling error will be well below the ten percent specified at the beginning of the study.

Appendix I: Testing the Accuracy of the CALSCAN Classifier

The accuracy of the CALSCAN system to classify ERTS-1 data into land use and timber volume classes was evaluated by comparing these classifications with those made by interpreters on aerial photos at two scales. First, the classified ERTS-1 data were compared with the photo plot estimates of timber volume classes on aerial photos of a scale of 1:1,000. Timber volume estimates were made at sixty-two photo plots located throughout the Plumas National Forest. Estimates of timber volume were assigned by photo interpreters to one of four timber volume classes: (1) non-forest, (2) less than 10,000 board

TABLE 4.12. COST ESTIMATE -- TIMBER INVENTORY -- BASED ON 215,000 ACRES, QUINCY RANGER DISTRICT

COMPUTER PROCESSING		
CALSCAN TRAINING AND PHOTO INTERPRETATION	$120	
CALSCAN CLASSIFICATION	210	
STATISTICAL BREAK-UP	40	
CALSCAN STATISTICS	12	
		$382
AERIAL PHOTOGRAPHY		
AIRCRAFT AND CREW	$210	
FILM AND PROCESSING	90	
		$300
SUPPLIES AND EXPENSES		
TRAVEL	$350	
MISCELLANEOUS	50	
		$400
PERSONNEL		
1 PROJECT SCIENTIST, 2 MOS. F.T.E. @ $1,100/MO.	$2,200	
1 SOFTWARE CONSULTANT, ½ MO. F.T.E. @ $1,300/MO.	650	
1 STATISTICIAN, ½ MO. F.T.E. @ $1,100/MO.	550	
2 LAB ASSISTANTS, 1 MO. F.T.E. EACH @ $620/MO.	1,240	
SALARY SUBTOTAL	$4,640	
ASSOCIATED OVERHEAD @ 20%	$968	
		$5,568
TOTAL		$6,640

feet per acre, (3) 10,000 to 20,000 board feet per acre, and (4) greater than 20,000 board feet per acre. The points corresponding to each photo plot center were carefully transferred to the ERTS-1 classified data, and a comparison made of the two timber volume estimates associated with each point. Table 4.13 shows the results of this comparison. The correct classifications of points in the non-forest and the less than 10,000 board feet per acre classes were 90 and 93 percent, respectively. The correct classifications of points in the 10,000-20,000 and greater than 20,000 classes were 67 and 75 percent, respectively. In the second case the class assigned to each picture element within the ERTS-1 training cells by the discriminant analysis was compared with the photo interpreter's delineation and assignment of the timber volume classes on the 1:120,000 color infrared photography used to train the classifier. These results are tabulated in Table 4.14. The percentages of correctly classified ERTS picture elements were observed to be 91.4, 70.0, 51.3, and 57.5 respectively for the four timber volume classes.

The Wilcoxon rank sign test was used to determine whether the overall classification accuracy of the ERTS-1 data when compared with that obtained with aerial photos at a scale of 1:1,000 and 1:120,000 was equivalent. The Null hypothesis is that there is no difference between the overall classification accuracies. Based on the Wilcoxon test (see Table 4.15) the Null hypothesis was accepted, indicating that there is no significant difference in the overall classification accuracies.

TABLE 4.15. RESULTS OF WILCOXON RANK-SIGN TEST.

Difference	.1	1.4	−2.0	2.4	2.9	3.8	3.9	5.0
Rank	1	2	−3	4	5	6	7	8
Difference	−5.4	6.3	6.3	9.0	10.4	14.4	−17.5	−23
Rank	−9	10.5	10.5	12	13	14	−15	−16

$|-43| \geq 20$ accept the Null hypothesis that the two tests are not significantly different.

Although there is no significant difference in the overall classification accuracies, there is a numerical difference between the classification accuracies associated with the individual volume classes. For

TABLE 4.13. COMPARISON OF CLASSIFIED ERTS DATA WITH A PHOTO INTERPRETER'S CLASSIFICATION THAT WAS MADE AT A PHOTO SCALE OF 1:1,000.

Discriminant Analysis

Photo Interpretation on 1:1000 color photography	NF	T1	T2	T3
NF	90.0	5	0	5
T1	0	93	7	0
T2	7	19	67	7
T3	0	0	25	75
% change in class	+5%	+20	-7%	-8

NF = Non forest

T1 = Less than 10,000 board feet per acre

T2 = 10,000 to 20,000 board feet per acre

T3 = Greater than 20,000 board feet per acre

The diagonal of the matrix shows the percentage correct classifications when comparing the discriminant analysis of ERTS data with the large large scale photographs on the assumption that the latter corresponds to "ground truth". The values not along the diagonal represent the percentages of points classified by discriminant anlysis of ERTS-1 data which were greater than, (+), or less than, (—), the points classified by interpreters on the large scale aerial photographs.

TABLE 4.14. COMPARISON OF CLASSIFIED ERTS DATA WITH A PHOTO INTERPRETER'S CLASSIFICATION THAT WAS MADE AT A PHOTO SCALE OF 1:120,000.

Discriminant Analysis

Photo Interpreter Typing on 1:120,000 CIR photography	NF	T1	T2	T3
NF	91.4	5.1	2.4	1.1
T1	9.0	70.0	17.1	3.8
T2	9.6	18.0	51.3	21.1
T3	6.3	6.3	30.0	57.5
% change in class	+16.3	-.6	+.8	-16.5

NF = Non forest land

T1 = Less than 10,000 board feet per acre

T2 = 10,000 to 20,000 board feet per acre

T3 = Greater than 20,000 board feet per acre

The diagonal of the matrix shows the percentage correct classifications when comparing the discriminant analysis of ERTS data with the small scale photographs on the assumption that the latter corresponds to "ground truth". The values not along the diagonal represent the percentages of points which were erroneously classified into other timber volume classes. The values at the bottom of the columns indicate the percentages of points classified by discriminant analysis of ERTS data which were greater than, (+), or less than, (—), the points associated with training cells which were delineated by photo interpreters on the small scale aerial photographs.

example, the diagonal values in Table 4.13 are generally higher than the diagonal values in Table 4.14, suggesting that the classified ERTS-1 picture elements compare more accurately with the timber volume class estimates made from aerial photos at a scale of 1:1,000, than they do with the class estimates made from aerial photos at a scale of 1:120,000. This observation may be explained in part by the difficulty of locating and delineating homogeneous training cells on the 1:120,000 scale high altitude aerial photographs. Each training cell was chosen because it was as homogeneous as could be found, but even then one cannot expect to find homogeneous stands of a size that is practical for the photo interpreters to delineate. Therefore, the classified ERTS-1 picture elements associated with a training cell may well be more accurate on a point by point basis than the classification assigned to the training cell by the photo interpreter.

It should also be noted that most of the classification errors occurred between adjacent volume classes. For example, a look at volume class T2 in Table 4.14 shows that 18 percent of the ERTS picture elements associated with volume class T2 were classified into volume class T1, while 21 percent were classified into volume class T3. This type of error seems to be consistent with the expected variability one might encounter when attempting to delineate homogeneous timber volume classes.

The resource manager is also interested in vegetation classes which are non-timber. Such classes are important in determining non-productive land, areas suitable for reforestation, areas of range land utilization, or wildland fire hazards, and those in need of watershed protection. Figure 4.18 shows a portion of the results of the discriminant analysis of ERTS date from the Plumas National Forest. The ERTS data has been placed into seven classes, six of which are non-timber. Table 4.16 shows the classification accuracies obtained for each of the seven categories when the classified ERTS picture elements were compared with the training cells delineated on small scale (1:120,000) color infrared aerial photographs. It is apparent from the results that there is a high correlation for some classes using the two classification methods while there is a low correlation for other classes, those having the highest percentage correct are generally those which are most homogeneous in appearance. Those classes with a lower percentage correct were generally non-uniform (heterogeneous) in appearance producing spectral signatures which overlap with one of more of the other categories. For example, the "conversion" class is made up of brush, bare soil, grass, regeneration and hardwood.

Appendix II. Statistical Methods for Timber Volume Estimation

Timber volume predictions were made from three stages of the timber inventory of the Quincy Ranger District for the purpose of selecting

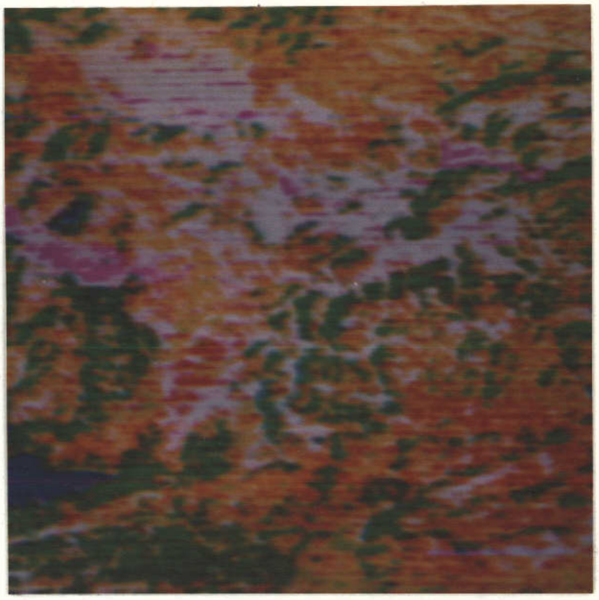


Figure 4.18. The discriminant analysis of classified ERTS-1 data for a portion of Plumas National Forest. Six non-timber classes and one timber class were produced using the CALSCAN system. Table 4.16 presents a quantitative comparison of the classified ERTS picture elements with photo interpreter classified training cells delineated from small scale aerial photographs (1:1,120,000).

Legend:

Conifer	=	Light green
Soil	=	White
Rock	=	Purple
Brush	=	Red
Hardwood	=	Red
Water	=	Blue
Conversion	=	Pink
Grassland, meadow	=	Mustard
Red fir	=	Blue green
Serpentine	=	White

TABLE 4.16. RESULTS OBTAINED IN COMPARING CLASSIFIED ERTS DATA WITH PHOTO INTERPRETER-CLASSIFICATION OF LAND-VEGETATION CATEGORIES ON SMALL SCALE AERIAL PHOTOGRAPHS (1:120,000).

Discriminant Analysis of ERTS-1 data

Photo Interpretation on 1:120,000 CIR and ground data	Coni	Soil/R	BR	H.W.	Wat.	Conv.	Grass
Coni	95.7	.9	0	3.8	0	0	.9
Soil/R	0	71.8	0	14.1	0	7.0	7.0
BR	14.3	0	48	13.0	0	1.3	23.4
H.W.	13.2	.9	1.9	74.5	0	3.8	5.7
Wat.	0	0	0	0	100	0	0
Conv.	12.5	12.5	0	43.8	0	31.25	0
Grass	15.6	9.4	3.1	6.35	0	6.3	59.4
% change in class	+5.6	-16.9	-48.1	+13.2	0	+6.25	+59.4

CONI = Commercial conifer consisting of pure fir and mixed conifer stands.

SOIL/R = Soil and Rock.

BR = Brush lands made up several species in mixed and pure stands.

HW = Hardwoods included Oak and riparian.

WAT = Water.

CONV = Brush lands converted to conifer plantations.

GRASS = Grass lands included dry and wet meadows.

The diagonal of the matrix shows the percentage correct classifications when comparing the discriminant analysis of ERTS data with the training cell classes delineated on the small scale photographs. The values not along the diagonal represent the percentages of points which were erroneously classified by discriminant analysis which were greater than, (+), or less than, (−), the points associated with the training cells.

sample plots whose probability of selection would be proportional to the volume predictions. Thus, variable probability sampling methods were used to estimate the total volume in this timber inventory.

Three variables proportional to timber volume were used in generating the selection probabilities: (1) "volume" estimates of the ERTS picture elements based on the spectral signatures on four bands and subsequent training and classification; (2) volume estimates of plots on 1:1,000 scale color prints, based on photo-volume tables (Chapman, 1965)* and (3) volume estimates on large scale photos, based on crown diameters cubed.

When one uses a scheme where probability of selection is proportional to the estimated volume, the effort is focused on the areas of higher timber volume and thus adds to the overall cost-efficiency. The ability to list the populations at each stage prompted the selection of list sampling as the variable probability sampling scheme.

Method of Estimation

The method of estimation was based on "unequal expansion" as implied by the probability scheme discussed above. At each of the three stages, the probability-proportional-to-estimated-size (p_i) was obtained by listing the volume estimates of the sampling units (x_i), and dividing them by the total of volume estimates ($\sum_{i=1}^{n} x_i$):

$$p_i = \frac{x_i}{\sum_{i=1}^{n} x_i}$$

A sample of a chosen size was then drawn by applying random integers from 1 to $\sum_{i=1}^{n} x_i$ and observing the probability interval and the corresponding sampling unit which contains the randomly selected integers.

In the first and second stages the timber volumes of the selected sampling units were estimated by subsequent sampling, whereas in the third stage the volume was carefully measured by a precision dendrometer. The entire three stage estimation procedure was as follows:

Stage I: A sample of n_h out of the N_h PSU's was drawn from stratum h with probability proportional to estimated size (ppes). The estimate

* Chapman, Roger C. 1965. Preliminary Aerial Photo Stand-Volume Tables for Some California Timber Types. Pacific Southwest Forest and Range Experiment Station Research Paper No. 93. 9 pp.

of the total volume then became: $\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{y_{hi}}{p_{hi}}$

where: L = total number of strata

p_{hi} = selection probability of the $i^{\underline{th}}$ PSU in the $h^{\underline{th}}$ stratum

y_{hi} = total volume of the $i^{\underline{th}}$ PSU in the $h^{\underline{th}}$ stratum (remains to be estimated by subsequent stages).

Stage II: To estimate the total volume (y_{hi}) of the $i^{\underline{th}}$ PSU, a sample of n_{hi} out of the N_{hi} secondary sampling units (.4 acre plots) was drawn with ppes. This gave:

$$\hat{y}_{hi} = \frac{1}{n_{hi}} \sum_{j=1}^{n_{hi}} \frac{y_{hij}}{p_{hij}}$$

However, in order to include area expansion from circular sample plots to the full PSU, and also to stratify the second stage plots into four volume strata, the estimator became:

$$\hat{y}_{hir} = \sum_{r=1}^{R} \frac{1}{p_{hir}} \frac{A_{hir}}{a_{hir}} \frac{1}{n_{hir}} \sum_{j=1}^{n_{hir}} \frac{\hat{y}_{hirj}}{p_{hirj}}$$

where: $r = 1,2,\ldots,R$ refers to the CALSCAN volume strata

p_{hir} = selection probability of the $r^{\underline{th}}$ volume stratum of the $i^{\underline{th}}$ PSU in the $h^{\underline{th}}$ stratum

A = area (indexes as above)

a = sampled area (indexes as above)

n = sample size (indexes as above)

p_{hirj} = selection probability of the $j^{\underline{th}}$ plot of the $r^{\underline{th}}$ volume stratum, of the $i^{\underline{th}}$ PSU in the $h^{\underline{th}}$ stratum

$\hat{y}_{hirj}$ = plot volume (to be estimated by stage III)

Stage III: To estimate the total volume of the $j^{\underline{th}}$ plot, a sample of n_{hirj} out of the N_{hirj} tertiary sampling units (trees) was drawn with ppes. Then:

$$\hat{y}_{hirj} = \frac{1}{n_{hirj}} \sum_{k=1}^{n_{hirj}} \frac{y_{hirjk}}{p_{hirjk}}$$

where: p_{hirjk} = the selection probability of the $k^{\underline{th}}$ sample tree of the $j^{\underline{th}}$ plot of the $r^{\underline{th}}$ volume stratum of the $i^{\underline{th}}$ PSU of the $h^{\underline{th}}$ stratum.

y_{hirjk} = the dendrometer-measured volume of the $k^{\underline{th}}$ sample tree of the $j^{\underline{th}}$ plot of the $r^{\underline{th}}$ volume stratum of the $i^{\underline{th}}$ PSU of the $h^{\underline{th}}$ stratum.

Combining the various stages above, the entire estimator became:

$$\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \sum_{r=1}^{R} \frac{1}{p_{hir}} \frac{A_{hir}}{a_{hir}} \frac{1}{n_{hir}} \sum_{j=1}^{n_{hir}} \frac{1}{p_{hirj}} \frac{1}{n_{hirj}} \sum_{k=1}^{n_{hirj}} \frac{y_{hirjk}}{p_{hirjk}}$$

Variance of the Estimator

In multistage sampling, when the number of first stage units is large, most of the variability in the population is due to the first stage. Therefore, it suffices to consider only the first stage values (here y_{hi}) to estimate the population variance and, consequently, the variance of the estimator (Durbin, 1953, p. 262; Kendall and Stuart, 1967, vol. 3, p. 200; Langley, 1971, p. 131).

Thus, for the first stage our stratified sampling estimator becomes (Cochran, 1963, p. 260):

$$\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{y_{hi}}{p_{hi}}$$

Its variance is:

$$\text{Var}\,(\hat{V}) = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{N_h} p_{hi} \left(\frac{y_{hi}}{p_{hi}} - V_h \right)^2$$

which has an unbiased estimator:

$$\hat{\text{V}}\text{ar}\ (\hat{\text{V}}) = \sum_{h=1}^{L} \frac{1}{n_h\ (n_h - 1)} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{p_{hi}} - \hat{V}_h\right)^2$$

For proportional allocation, $n_h = n(N_h/N)$ and

$$\text{Var}\ (\hat{V}) = \sum_{h=1}^{L} \frac{N}{n\ N_h} \sum_{i=1}^{N_h} p_{hi} \left(\frac{y_{hi}}{p_{hi}} - V_h\right)^2$$

$$\hat{\text{V}}\text{ar}\ (\hat{V}) = \sum_{h=1}^{L} \frac{N^2}{n\ N_h\ (nN_h - 1)} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{p_{hi}} - \hat{V}_h\right)^2$$

The last equation is an unbiased estimator of Var $(\hat{V})$ and can be used for the estimation of the sampling error of the inventory.

Sample Size

(a) From the usual confidence statement

$$P\ \{\hat{V} - t_{\alpha;\ n-1} \sqrt{\text{Var}(\hat{V})} < \mu \leq \hat{V} + t_{\alpha;\ n-1} \sqrt{\text{Var}(\hat{V})}\ \} = 1 - \alpha$$

To obtain n for a fixed precision level (d), e.g. 5% of Y at 95% confidence level, proceed as follows:

Let $d = t\sqrt{\text{Var}(\hat{V})}$, i.e. half-width of conf. int., also called "allowable error"

$d^2 = t^2\ \text{Var}(\hat{V})$.

Since

$$\text{Var}(\hat{V}) = \frac{1}{n} \underbrace{\sum_{i}^{N} p_i \left(\frac{y_i}{p_i} - V_h\right)^2}_{S^2}$$

Then

$$d^2 = \frac{t^2 S^2}{n}$$

And

$$n = \frac{t^2 S^2}{d^2}\ .$$

The value of S^2 was unknown in this application, and had to be

estimated. Recalling that the population consists of N primary sampling units as a result of the partitioning of the forest in ERTS image, the population variance S^2 is obtained by

$$S^2 = \frac{1}{N}\sum^{N}(y_i - \bar{y})^2$$

where y_i denotes the total volume of the $i^{\underline{th}}$ PSU, and $\bar{y}$ their average.

The CALSCAN classification provided a means of estimating the value of y_i for each PSU, since each picture element had been assigned to a volume class. Thus the weighted sum of these gave the total volume of the PSU. More formally,

$$y_i = \sum_{l}^{n}\sum_{k}^{m} w \cdot c$$

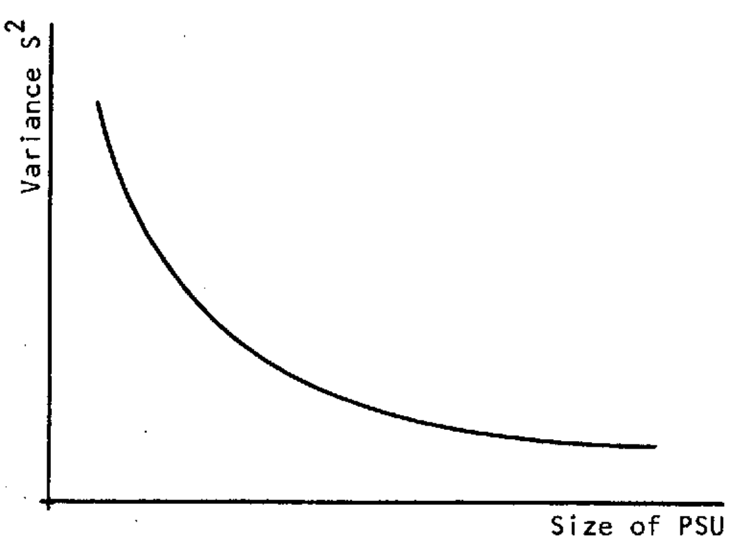
where $k = 1, \ldots, m$ is no. of rows of picture elements in PSU

$l = 1, \ldots, n$ is no. of columns of picture elements in PSU

w = volume weight for c

c = CALSCAN class assigned to the $kl^{\underline{th}}$ picture element

This approach also enabled a study of optimum size and shape of the PSU. Using the variance S^2 as a criterion and varying the size of the PSU, the following relationship was obtained:



Similarly, by varying the width and length for a fixed size of the PSU,

and observing the S^2, respectively, the optimal width/length ratio was found. The outcome of this particular study had to be qualified by practical considerations, e.g., those related to the procurement of the aerial photos of PSU's for subsequent sampling.

As a result, a rectangle of size (43 x 5) picture elements (1325' x 1.5 mi.) was selected to be used for each PSU in the survey.

Using the coefficient of variation (CV) and 95 percent level of confidence, the number of PSU's was found by,

$$n = \frac{t^2 \cdot (CV)^2}{d^2}$$

Actually, for small sample sizes, the t-value changes with the n, and n has to be calculated by iterating with a few t-values.

<u>Example, Plumas National Forest</u>:

(1) Assume n = 13, then $t_{(n-1)} = 2.18$ at 95% level.

Assume CV = .18

Let $d = t\, s_{\bar{x}} = .10$ (allowable error, i.e. half width of conf. int.)

Then

$$n = \frac{t^2(CV)^2}{d^2} = \frac{(2.18)^2\ (0.18)^2}{(0.10)^2} = \frac{0.154}{0.01} = 15.4 \approx 16.$$

<u>Second iteration</u>: Assume n = 15, then $t_{(n-1)} = 2.13$ at 95% level

$$n = \frac{(2.13)^2(0.18)^2}{0.01} = \frac{0.147}{0.01} = 14.7 \sim 15.$$

(2) Assume n = 60, then $t_{(n-1)} = 2.00$ at 95% level

Let $d = t \cdot s_{\bar{x}} = .05$, i.e. $s_{\bar{x}} = 2.5\%$

Then

$$n = \frac{(4)\ (0.0324)}{0.0025} = \frac{0.1296}{0.0025} = 51.8 \approx 52.$$

4.2.5 Conclusions -- Feather River Watershed

Three primary objectives were established for the work done within the Feather River watershed, and they were (1) to acquire supporting ground data of the necessary kind, amount, distribution and frequency for making reliable evaluations of the ERTS-1 imagery, (2) to test various components of the ERTS-1 system for information content relative to defined user requirements, and (3) to test the practical applications of ERTS-1 imagery and supporting data for meeting specific user requirements. The following conclusions were reached with respect to each of these objectives:

1. Four methods of ground data collection were used during the study -- compiling existing data available, collecting new data at selected plot locations, interpreting and field checking aerial photography acquired by high performance NASA aircraft, and interpreting oblique and vertical 35 mm aerial photography taken from a low flying single engine aircraft. Ground data collected by these different methods were effectively used in each study done with ERTS-1 data. For example, field plot data and a vegetation/terrain map prepared from high flight photography were the base to which maps prepared from ERTS-1 imagery were compared. In addition, 35 mm aerial photos taken from a low flying aircraft were effectively used, not only to verify analyses done on ERTS-1 imagery, but also as intermediate stages of data input to a multistage sample design for estimating timber volume.

2. Various components of the ERTS-1 system were tested using manual interpretation techniques. For example, when MSS bands 4, 5 and 7 and a color composite print were evaluated and the interpretation results presented in a feasibility diagram, it was concluded that a skilled interpreter can detect wildland resources acceptably well on ERTS-1 imagery; however, resource identification is much more difficult. In another test, a color composite transparency was analyzed, and it was concluded that a skilled photo interpreter could correctly detect and identify sixteen specific resource types 67 percent of the time. When various color composite images and an electronically enhanced image were analyzed for classifying commercial conifer forest types, it was found that a three-band electronic enhancement and a two-band color composite significantly were best, rather than band no. 5 or a three-band color composite. However, when three ERTS-1 image-date types were tested in terms of vegetation/terrain type identification, no statistical differences could be found between the three types, and a "best" image-date type could not be chosen.

3. Two quasi-operational studies were performed to show the practical utility of ERTS-1 data.

a. A demonstration project was performed which showed that ERTS-1 imagery is ideal for making vegetation/terrain type maps -- similar to

the map made by the California Comprehensive Framework Study Committee -- over vast inaccessible wildland areas. In this demonstration project the levels of accuracy associated with the Framework Study map and the ERTS-1 map were 68 percent and 81 percent, respectively. Moreover, the Framework Study map was compiled using both current and outdated data, but when following identical mapping objectives, the ERTS-1 map required only 11.5 hours of interpretation time. Lastly, the demonstration study proved that not only can a more timely and more accurate regional vegetation/terrain map be prepared from ERTS-1 imagery than from using conventional methods (i.e., the Framework Study), but also the ERTS-1 map can be prepared at approximately one-third the cost.

b. A demonstration project was performed which showed that a timber inventory based on manual and automated analysis of ERTS-1 and supporting aircraft data could be made using multistage sampling. The objective of the inventory was to estimate the standing volume of merchantable timber within the Quincy Ranges District (215,000 acres) of the Plumas National Forest. A three-stage sampling desing was used whereby (1) the first stage involved automatic classification of ERTS-1 data tapes and selection of primary sampling units, (2) the second stage involved acquisition of large scale aerial photos over selected primary sampling units and selection of photo plots based on manual interpretation, and (3) the third stage involved visiting selected photo plots on the ground and selection of trees to be measured for timber volume. When the tree volumes were expanded through the various stages of the sample design, total timber volume for the Quincy Ranger District was estimated to be 2.44 billion board feet with a sampling error of 8.2 percent. Cost per acre for the inventory procedure at 1.1 cent/acre compared favorably with the costs of a conventional inventory done by U.S. Forest Service personnel within the same area at 25 cents/acre. In addition, a point-by-point comparison of CALSCAN classified ERTS data with manually interpreted low altitude photo plots indicated no significant differences in the overall classification accuracies. Thus, a multistage timber inventory using ERTS-1 imagery for the first stage proved to be a timely, cost-effective alternative to conventional timber inventory techniques.

4.3. ANALYSIS WITHIN THE NORTHERN COASTAL ZONE OF CALIFORNIA

4.3.1 Introduction

Within recent years, California's coastal land has come under mounting pressure by (1) developers who want to convert portions of the relatively undeveloped coast line into home sites for prospective buyers, (2) recreationists, who want to experience the beauty of the coastal region and gain access to the shoreline without hindrance from private land owners, (3) resource users who are converting the abundant vegetative and water resources into products for human consumption, and (4) utility companties, who seek sites for power generating facilities. Because the expected intensification of resource use in the north coast region could lead to serious environmental problems, the people of California enacted the Coastal Zone Conservation Act in November, 1972. This act created a California Coastal Zone Commission which will use $5 million in state funds and $15 million in federal funds to generate a land use plan (California Coastal Zone Conservation Plan) for the preservation, restoration, orderly development and enhancement of California's coastal zone.

The most important prerequisite for intelligent land use planning will be the preparation of an integrated inventory and evaluation of the physical and biological characteristics of the coastal region as they affect various types of land use. In this regard we have conducted a remote sensing study of the usefulness of aircraft and spacecraft imagery (ERTS-1) for preparing integrated resource inventories and for monitoring significant changes in the physical and biological environment of the North Coast of California.

The North Coast Test Site encompasses the entire area (10,362 square miles) within the five coastal counties of northern California between San Francisco's Golden Gate and the Oregon border, viz., Marin, Sonoma, Mendocino, Humboldt, and Del Norte. (See Figure 4.19) The northern portion of the test site may be characterized as timbered, mountainous terrain where activities concerned with timber harvesting and processing constitute the mainstay of the economy. The southern portion of the test site contains less mountainous terrain and consists of many developed urban centers, interspersed with grazing and agricultural land. The length of coast bordering on the west edge of the test site is 418 miles, or approximately 39 percent of California's coast line. This coastal area is rated as the most beautiful in the state.

Remote sensing studies are being performed in two intensive study sites within the North Coast Test Site: (1) the <u>northern study site</u> encompassing a swath of coastal land extending inland some 10-15 miles, from Cape Mendocino to the Humboldt-Del Norte County line, and (2) the <u>southern intensive test site</u> including the area encompassed by Sonoma and Marin Counties.

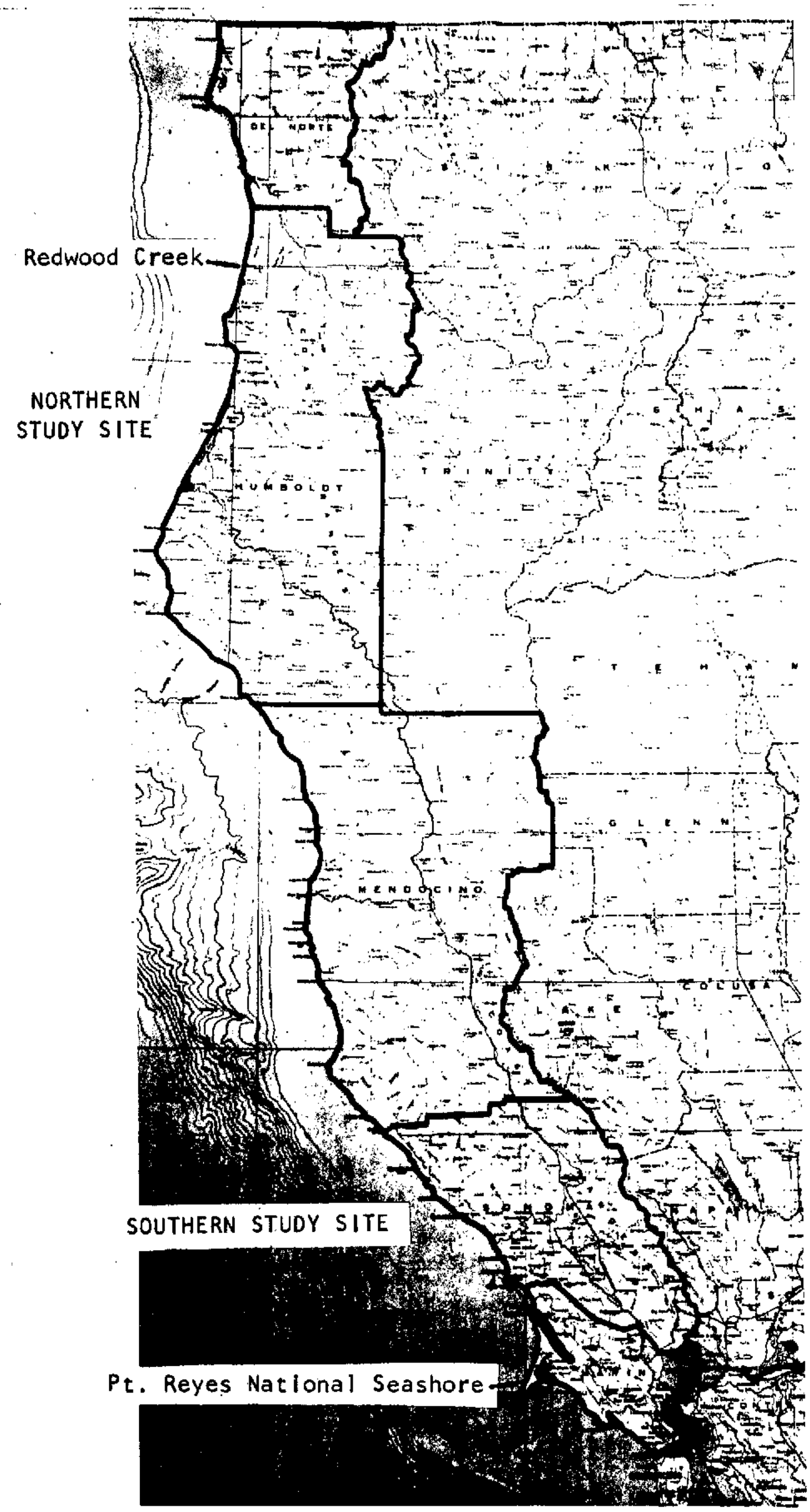


Figure 4.19. North Coast Test Site showing northern and southern study sites and specific areas analyzed on ERTS and U-2 imagery.

4.3.1.1 Objectives

The primary purpose of this investigation was to evaluate the usefulness of remote sensing data in providing general land use planning information pertaining to the wise management of resources along the north coast of California. It was anticipated that much information of direct benefit to resource managers and developers within the area would be derived. (Table 4.17 indicates many of the agencies and managers we have worked with in this study.)

More specifically, the objectives of this study were: (1) to determine the level of accuracy, the time and the costs to prepare a land use inventory using human interpreters; (2) to determine the level of accuracy and detail for classifying significant land use categories using automatic interpretation techniques; (3) to determine which bands, dates, and combination of bands and dates of imagery obtained by the ERTS-1 system would provide the optimum data base for generating land use maps; and (4) to determine which of the various biological and physical features that exhibit change over time could be discriminated and monitored.

A significant undertaking required before these objectives could be attained involved an enumeration of those parameters which are of particular importance to environmental planners in determining the potential of an area in terms of land use, be it natural resource utilization, open space preservation, urban expansion, or industrial development. Interaction between the CRSR and planners (See Table 4.17) currently involved in the formulation of long range land use plans for the coastal region of California was necessary for this undertaking.

The remainder of this report on the North Coast Test Site describes the reasearch activities which have been conducted to satisfy the objectives of this project. They include: (a) compilation of a classification scheme which includes the environmental parameters of particular importance to land use planners; (b) human analysis of land use categories in the southern study site and (c) human analysis of resource problems associated with the redwoods in the northern study site using U-2 and ERTS-1 data.

4.3.1.2 North Coast Environmental Planning and Classification Data

One of the objectives of the North Coast Study was to determine the feasibility of using the information obtained from remote sensing as an aid to regional environmental planners for planning the orderly development of this area. In order to accomplish this task, it was necessary to identify the inputs which are or could be utilized in the planning process, and then assign relative weights to these inputs in terms of their significance to the planners' objectives. The next requirement was to compare this weighted list of desired inputs with a list of that information which physically could be derived through the

TABLE 4.17. USER AGENCY INTERACTION (NORTH COAST REMOTE SENSING PROJECTS).

USER GROUP AGENCY	PERSONNEL CONTACTS	REMOTE SENSING APPLICATION/INFORMATIONAL REQUIREMENTS
U.S. DEPARTMENT OF INTERIOR		
National Park Service	Richard Brown (Pt. Reyes Natl. Seashore)	Vegetation/terrain mapping of National Seashore
	John H. Davis, Supt. Ted Hatzimanolis (Redwood National Park)	Cooperative agreement to analyze U-2 and ERTS imagery for resource management purposes
	John Adams (Western Regional Office)	
U.S. Geological Survey	Richard Janda, Steve Coleman (Menlo Park)	Cooperative studies of U-2 and ERTS imagery of Redwood National Park resource management problems
Bureau of Outdoor Rec.	James Mills (San Francisco)	Assessment of recreation areas using remote sensing techniques
U.S. DEPARTMENT OF AGRICULTURE		
Forest Service	James Cook (P.S.W. Forest and Range Exp. Station)	Use of remote sensing techniques for producing California Comprehensive Framework Study Data
Soil Conservation Service	Walter Bunter (Berkeley)	Use of ERTS and high flight data for regional land use mapping
CALIFORNIA STATE DEPARTMENT OF CONSERVATION	Ray Jackman (Jackson State Forest)	Providing maps and resource data for forest land mapping comparisons
CALIFORNIA WATER RESOURCES CONTROL BOARD	Gilbert Fraga (Division of Planning and Research)	Aerial photo reconnaissance systems for evaluating impact of prospective logging and land use conversion operations on water quality
CALIFORNIA DEPARTMENT OF NAVIGATION AND OCEAN DEVELOPMENT	Glenn Twitchell (Comprehensive Ocean Area Plan)	Selection of mapping categories and aerial photo techniques for land use mapping in coastal zone of California
CALIFORNIA GOVERNOR'S OFFICE	John Passerelo (Office of Planning and Research)	General resource planning applications of remote sensing; location of critical resource areas within the state

TABLE 4.17. (CONTINUED)

USER GROUP AGENCY	PERSONNEL CONTACTS	REMOTE SENSING APPLICATION/INFORMATIONAL REQUIREMENTS
COASTAL ZONE CONSERVATION COMMISSION	Dave Dubbink (North Central Coast Regional Comm.)	Remote sensing applications for land use planning, monitoring and enforcement
	Jack Lahr Mike Garabedian (North Coast Regional Commission)	" " " " " " "
COUNTY GOVERNMENTS:		
Marin County	Ruth Corwin Ellis Gans (Planning Department)	Mapping of land use and natural resources for planning purposes; monitoring of environmental changes
Sonoma County	Richard Jacobs Frank Balthis (Advanced Planning Dept.)	Detailed land use mapping, using aerial photographs
OTHER GOVERNMENT AGENCIES		
Association of Bay Area Governments (ABAG)	Ray MacAllister Alan Black Stephanie Wilson (Planning Team)	Use of high flight imagery and ERTS tapes for regional planning in San Francisco Bay Area
Agricultural Extension Service (cooperative between USDA, U.C., and Humboldt County)	Paul Smith (Forest Advisor)	Education of forest managers in use of remote sensing techniques
NON-GOVERNMENT AGENCIES		
Arcata Redwood Co. (Arcata, California)	Eugene A. Hofsted, Jr. (Chief Forester) Lou Torrano (Forester)	Use of U-2 imagery as a tool for evaluating timber harvesting and management activities.
Louisiana Pacific Corp. (Big Lagoon Operation, Samoa, California)	Alfred H. Merrill (Chief Forester)	" " " " " " "
Rellim Redwood Co. (Crescent City, Calif.)	Dick Brown (Chief Forester)	" " " " " " "
Simpson Timber Co. (Arcata, California)	Herb Peterson (Chief Forester) Charles Evers (Logging Engineer and Surveyor)	" " " " " " "

analysis of remote sensing data. This second list needed to be weighted according to the cost, the time and the level of accuracy associated with generating the desired information from the remote sensing data. In this manner, an "optimum" remote sensing system could be developed to assist regional planning. The steps which were taken to determine the information requirements of regional planners are presented in the remainder of this section.

In an area as large and diverse as the North Coast Test Site, no one regional planning agency has objectives and data requirements which would satisfy all north coast planners' needs. The agency which most closely met these criteria in the north coast area was a temporary state government body set up from within the Department of Navigation and Ocean Development (the Interagency Council for Ocean Resources) which cooperated with other state resource agencies and county planners in the creation of the California Comprehensive Ocean Area Plan (COAP). The major shortcoming of the data requirements outlined is to be found in the fact that the plan dealt exclusively with a narrow and sometimes arbitrarily defined area immediately adjacent to the beach or coast (essentially as specified in the Coastal Zone Conservation Act passed after COAP was completed). In order for planning needs to be met within the broader North Coast Test Site, additional data requirements had to be defined. A comprehensive list of desirable environmental data, see Table 4.18 (applicable throughout the north coast), was compiled after reviewing various planning documents. The primary sources used to develop the list of information needs were:

The California Comprehensive Ocean Area Plan (COAP), 1972. State of California, Department of Navigation and Ocean Development, Interagency Council for Ocean Resources.

Supplement to COAP, 1972. State of California, Department of Navigation and Ocean Development, Interagency Council for Ocean Resources.

California Coastline -- Preservation and Recreation Plan, 1971. California Department of Parks and Recreation (in cooperation with COAP).

Fish and Wildlife in the Marine and Coastal Zone, 1971. California Department of Fish and Game (in cooperation with COAP).

Ocean Coastline Study, 1970. Association of Bay Area Governments (ABAG).

Can the Last Place Last, Preserving the Environmental Quality of Marin, 1971. Marin County Planning Department.

Mendocino County General Plan, Planning Division, Department of Public Works.

TABLE 4.18. PARAMETERS OF IMPORTANCE TO ENVIRONMENTAL PLANNERS FOR DETERMINING THE POTENTIAL OF AN AREA IN TERMS OF LAND USE.

I. Site Characteristics or Physical Attributes

A. Landforms
- Beaches (rocky and sandy)
- Cliffs, steep slopes, some land slides
- Dunes
- Island
- Mud flat
- Sea stack, rookery
- Spit, bar
- Playas
- Marine terraces
- Swamp

B. Geology
- Parent material -- 9 geologic types on coast of California
- Faults -- monitor seismologic activity -- rank areas for hazard
- Aquifers
- Aquifer recharge areas
- Oil or gas fields, other mineral deposits

C. Pedology
- Soil type } stability (erodibility, compressibility)
- Soil drainage

D. Physiography
- Elevation, slope (steepness and form), aspect
- Intervisibility
- Exposure (shoreline): protected + exposed
- Access (shoreline): plains, low terrace, high terrace, hills
- Drainage net or pattern (delineate watershed)
- Flood plain

E. Water Bodies
- Open water -- estuary
- Open water -- lagoon
- Lakes and ponds
  - permanent
  - ephemeral
- Reservoirs
  - classify by type of dam } hazard ranking
  - classify by proximity to seismologic areas
- Rivers and streams (stream order)
- Tidal marsh
- Tidal flat
- Coves, bays
- Deep water access
- Springs

F. Marine Features
- Kelp beds
- Sediment plumes
- Water clarity
- Water temperature
- Waves and currents
- Depth
- Reefs
- Wildlife areas (abalone, fish, seals, otters, birds, etc.)

G. Primary Vegetation
- Species composition
- Density
  - stems/acre
  - percent crown closure
- Timber volumes

Examples of Primary Vegetation Classification

Natural Vegetation (COAP)		Biotic Communities (Calif. Dept. of Parks & Rec.)	Land & Marine Ecology (ABAG)
Barren	Nb	1. Redwood Forest	Vegetative Cover:
Coastal Forest	Nc	2. N. Coast Coniferous Forest	1. Conifefous Forest
Redwood Forest	Nf	3. Maritime Pine Forest	2. Hardwood Forest
Grassland	Ng	4. Mixed Evergreen Forest	3. Grass and Forbs
Hardwood	Nh	5. N. Coast Scrub	4. Chaparral & Mtn. Brush
Woodland Grass	Nj	6. Chapasral	5. Cultivated & Pasture
Kelp	Nk	7. N. Coast Grasslands	6. Barren
Marsh (salt)	Nm	8. Coastal Strand	7. Urban
Marsh (fresh)	Nn	9. Freshwater Marsh	Ecological Features:
Riparian	Nr	10. Coastal Salt Marsh	Extent of Abalone
Coastal Sage	Ns	11. Sandy Intertidal Zone	Extent of Bishop Pine
Cut-Over Redwood	Nw	12. Rocky Intertidal Zone	Cormorant Nesting Areas
Other	Nz	13. Nearshore Zone	Sea Lion Rocks
		14. Urban	Gull Nesting Area
		15. Agriculture	Heron Rookery
			Eel Grass Beds
			Important Fishing Areas
			Clam Beds

H. Other Features or Phenomena
- Vegetation oriented
  - burned over areas
  - clear cuts
    - by tractor
    - by cable
  - insect and pathogen infestations
  - smog damage
  - fuel hazard for fires
  - windthrow along cutting boundaries or within selective logging areas
- Land oriented
  - landslides
  - stream aggradation and other changing stream conditions (e.g., amount of shade for water)
  - areas of tidal inundation likelihood (e.g., from hurricanes)
- Recreation oriented
  - historic/archeologic sites
  - unique sites or situations of high scenic appeal
- Wildlife oriented
  - monitor wildlife herd size
  - identify wildlife herd range and changes in range over time
- Climatic oriented
  - snowfall, fog occurrence (spatially and over time)
- Pollution oriented
  - air -- smoke, dust
  - water -- effluents, sediment loads, thermal
  - noise -- industrial, vehicular (proximity to likely sources of noise)
  - aesthetic -- clear cuts, cut and fill areas, urban blight

II. Land Use

A. Urban and Industrial
- Residential
  - density (families/net acre)
    - 0-1 very low
    - 1-5 low
    - 5-9 low-medium
    - 9-29 medium-high
- Industrial
  - manufacturing and warehousing
  - utility installations
  - extractive (mines, quarries, etc.)
- Military
  - bases and camps
- Commercial
  - business centers
  - urban recreation (bowling alleys, stadiums, race tracks)
- Transportation
  - highways and roads
  - airfields
  - harbor facilities
  - railroads
  - canals
- Institutions
  - universities and hospitals

B. Open Space
- Agricultural
  - Intensive -- cultivated or irrigated } could easily be expanded to include crop types, crop condition, etc.
  - less intensive -- grazing
- Commercial forest
- "Non-commercial forest" (wildland)
- Regional recreation (golf courses, ski areas, parks)
- Other non-developed areas

III. Land Ownership and Land Values

Recreation Plan, 1985, Sonoma County Planning Department.

Design with Nature, 1969. Ian L. McHarg.

Natural Vegetation and Land Use Classifications, 1972. Dr. J. Estes, et al. Geography Department, UC Santa Barbara.

Coastal Zone Conservation Act, Proposition 20, Public Resources Code, Section 27000 -- 27650, November, 1972.

Act Creating Redwood National Park in California. Public Law 90-545, 90th Congress, S. 2515. October 2, 1968.

Environmental Goals and Policy, State of California, John S. Tooker, Director. Office of Planning and Research, Governor's Office, March 1, 1972.

Program Design for San Francisco Bay Region Environment and Resources Planning Study. U.S.D.I. Geologic Survey and U.S. Dept. H.U.D. Research and Technology. Menlo Park, California. Oct., 1971.

The next step was to acquire "feedback" from the environmental planning agencies which deal with the problems created by the developmental demands being made on the North Coast Test Site. The type of feedback desired included (a) the suitability of the parameters for environmental planning, (b) the image scales, the frequency of data acquisition desired for each parameter and the relative value of each. Reactions to the list of parameters for environmental planning were received from county planners, coastal commissions, U.S. Forest Service, and U.S. Park Service resource managers and wood products industry personnel.

They grouped their information needs into "area-wide" and "sub-area" levels. These planners and resource managers listed the optimum image scales for obtaining both area-wide level and sub-area level types of information as follows:

optimum image scales for area-wide information:

1" = 2,000' to 8,000' (1:24,000 -- 1:96,000). For example:

1" = 2,000' is optimum for display map of a corridor
1" = 4,000' is optimum for entire county or planning unit
1" = 8,000' is optimum for county atlas, regional perspective and map format.

optimum image scales for sub-area level information

1" = 1,000' to 3,000' (1:12,000 -- 1:36,000)

Concern was expressed over the high costs of enlarging remote sensing imagery in order for it to be of maximum value, but the planners recognized the necessity for analyzing and interpreting remote sensing data at one scale and preparing or displaying maps at a different scale.

The planners and resource managers also provided a listing of basic information for regional planning. This included topography (e.g., slope categories and drainage patterns), soil type (e.g., stability and erodibility), vegetation types (e.g., timber, grass, brush, and marine), and geology (e.g., landslide and fault hazard areas). Also included were intervisibility studies (determination of area visible from any given vantage point) and the location of rare and/or endangered biotic communities or species.

A list of environmental parameters was prepared which planners felt should be monitored either periodically (mostly on an annual basis) or on short notice. The parameters which could be evaluated by remote sensing included: land use by slope classes; amount and type of development on unstable soil or subject to flood or fault hazard; annual amount of agriculture gone out of production; annual increase in developed land by category (e.g., residential, commercial, etc.); and areas of importance in maintaining high environmental quality. On the whole, the planners felt that the compilation of inventory data in Table 4.18 was desirable and beneficial for improved planning and management.

Having generated a complete listing of the important environmental parameters in the north coast, we recognize that it remains for image interpreters and remote sensing data analysts to determine the feasibility of providing information regarding those parameters in the desired format, within the desired time frame and for the desired cost. It is envisaged that the list of environmental parameters will serve as the basis for a workable classification scheme and for determining which resources can be identified on the different types of aircraft and spacecraft imagery. Interfacing a desirable classification scheme for the remote sensing data with the information requirements of regional planners in this area is one of the major tasks in which we currently are involved.

4.3.2 Analysis Within the Southern Study Site

4.3.2.1 Introduction

Sonoma and Marin counties comprise the southern intensive study area within the North Coast Test Site, and occupy an area of approximately 1,344,000 acres (2100 square miles) immediately north of and adjoining San Francisco Bay, California. This area is complex in both physiography and land use and includes considerable forest, range, pasture, and agricultural land (vineyards, apples and feed crops). It is dissected by two major river systems, and fronts on both San Francisco Bay and the Pacific Ocean. The impact of population pressure is evident by the

growing urbanization and transportation networks which spread along the southern edge of Marin County and into the interior valleys of Sonoma County.

Within the past year the California Coastal Zone Conservation Commission has been formed and charged with (1) studying the coastal zone to determine the ecological planning principles and assumptions needed to insure the conservation of the coastal zone resources; (2) preparing a comprehensive, coordinated, enforceable plan for the orderly, long-range conservation and management of the natural resources of the coastal zone, and (3) insuring that any development in the coastal zone (land area lying between the seaward limit of the state's jurisdiction and 1,000 yards landward from the mean high tide) during the study and planning period will be consistent with the objectives of the commission. This agency along with local and county planning commissions needs up-to-date, accurate, environmental information for land use inventory, monitoring and planning.

Analysis of remote sensing data, both on ERTS-1 and high altitude U-2 imagery, was carried out in two major areas of the southern intensive test site: (1) Sonoma County, and (2) the Point Reyes National Seashore, which forms the most westerly portion of Marin County.

The objectives for analyzing ERTS-1 imagery and high altitude aircraft data of this area are: (1) to determine what environmental or land use parameters can be delineated and classified on ERTS-1 imagery, and (2) to determine to what degree identification of these areas is possible on ERTS-1 alone and with the aid of supporting aircraft and ground data.

4.3.2.2 Land Use Mapping in Sonoma County

Sonoma County (see Figure 4.20) was chosen as a test site for the analysis of ERTS-1 data because: (1) it is a viable state political entity with a modern County Planning Department; (2) it has a combination of forest, agriculture, grazing, coastal and urban areas, allowing a variety of resources for interpretation on ERTS-1 and U-2 imagery; (3) cloud-free ERTS-1 imagery (July 27, 1972) of good quality for interpretation and color combination was available for immediate investigation; (4) an excellent U-2 high altitude flight (72-110, July 5, 1972) occurred close to the date of the ERTS pass, and (5) ground data were collected close to the time of the ERTS pass. Later in the study, updated land use maps were provided to this Center by the Sonoma County Planning Department for use as further ground control.

Procedures

The first step taken during the analysis of the ERTS-1 imagery of Sonoma County was to review the classification schemes described in the previous section. This review revealed that many of the informational requirements of regional planners could not be satisfied with the level

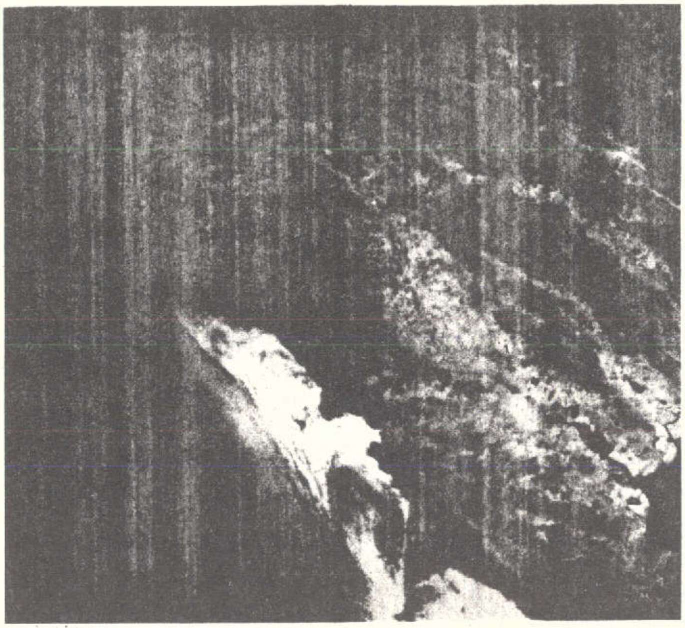


Figure 4.20. This ERTS-1 color composite image (July 27, 1972) of Sonoma County, California illustrates the delineation and classification of homogeneous-appearing areas. The text contains explanations and analyses of twenty-three land use vegetation/terrain type classifications applied to this region of the North Coast Test Site.

of information extractable from ERTS-1 imagery. Their needs would be better served by high altitude photography of higher resolution (as provided by the U-2 aircraft). It was felt, however, that generalized land use and vegetation/terrain maps could be prepared from the satellite imagery. These generalized maps could be of considerable value in less developed areas where a more general classification scheme still is adequate.

The second step in the analysis was to delineate the homogeneous areas visible on the ERTS-1 imagery. For this purpose, black-and-white ERTS-1 images from MSS bands 4, 5, and 7 were delineated based upon the tone, texture, and location of features. A diazochrome color composite, simulating a false-color infrared image, was prepared using three MSS bands; the composite was made by superimposing band 4 reproduced on yellow diazochrome film, band 5 reproduced on magenta diazochrome film, and band 7 reproduced on cyan diazochrome film. Then using color, texture, and location of features as clues, homogeneous areas were delineated and classified on the color composite.

The third step was to compare the delineations made on the ERTS-1 color composite with the high altitude photos taken on July 5 and October 6. To facilitate this comparison, the delineations made on the ERTS-1 color composite were transferred directly to the U-2 high altitude imagery by means of a Zoom Transfer Scope. Finally, the high altitude color infrared photographs were interpreted to verify the delineations and classifications made on the ERTS-1 color composite and to establish the true identity of many of the units delineated.

Results of the Analysis of the ERTS-1 Color Composite

Figure 4.20 shows the ERTS-1 color composite with the homogeneous units delineated. A description of each of the mapped units appears in Table 4.19. These descriptions are based primarily upon analysis of high altitude photography and ground data, rather than on interpretation of the ERTS-1 composite. The analysis of the ERTS-1 composite revealed that only a limited number of categories could be accurately or consistently identified, although the delineations, themselves, coincide quite closely with different land and environmental categories.

In general, healthy vegetation categories could be identified and differentiated from dry or unhealthy types. That is, forest and shrubland types could be distinguished from dry rangeland types. Differences within the healthy vegetation category attributed to plant density were readily apparent and delineated. Major river systems, specific urban complexes and agricultural land (see Table 4.19) were also among the broad categories which could be identified directly on the ERTS-1 color composite. With the aid of high altitude U-2 photography and a limited amount of ground data, all the categories (map units) delineated on the ERTS color composite were identified.

The twenty-three separate descriptions fall into eight general

TABLE 4.19. DESCRIPTION OF MAP UNITS DELINEATED ON THE ERTS-1 COLOR COMPOSITE IMAGE.

1. Forest: greater than 95% vegetated (based on proportion of ground area obscured by vegetation in the vertical view); little bare soil and/or rock outcrops, mountainous terrain. Species include canyon live oak, California black oak, bigleaf maple, madrone, red alder (California white oak and blue oak restricted to eastern county).
2. Forest: greater than 98% vegetated, little or no bare soil or rock outcrops, restricted to northern coastal hills. Species include a mixture of hardwoods and young conifers: bigleaf maple, madrone, bishop pine, tan-oak, Douglas fir, red alder, redwood.
3. Forest/Grassland: up to 10% open grassland and/or rock outcrops, mountainous terrain. Species composition similar to 1 above, increased open grassland being the major difference.
4. Forest/Grassland: 50-60% open grassland, in general occupying drier inland sites and mountainous terrain. Species composition Douglas fir, madrone, tan-oak, chinquapin.
5. Forest/Grassland: Grassland up to 20% total area, northern county, mountainous terrain. Some commercial conifers including Douglas fir, sugar pine; other species include tan-oak, chinquapin and oaks.
6. Forest/Grassland: Occupies inland mountainous terrain. Species composition similar to 4 above, but with less open grassland (less than 20%).
7. Forest: 90% commercial conifers; grassland less than 10%. Some coastal influence affects species composition (e.g., of bishop pine, Douglas fir, and redwood).
8. Agriculture: young orchard area along stream margin.
9. Agriculture: mixed agriculture on river valley flood plain, generally small fields, including dry and irrigated pasture, alfalfa.
10. Agriculture: large fields formed on reclaimed land, mature or harvested in July, thereby appearing bright white.
11. Agriculture: smaller fields planted to feed grains, scattered small orchards and residences.
12. Agriculture: Napa Valley vineyards.
13. Agriculture: primarily apple orchards located on river terraces.
14. Grassland/Brush: coastal chaparral type.
15. Grassland/Pasture: associated with interior foothills, dairy farms predominate.
16. Grassland/Pasture: similar to 15 but having less dairy farms, slightly drier sites than 15.
17. Grassland/Woodland: interior foothills, annual grassland are predominant on slopes while oaks dominate in drainages and on hilltops.
18. Oak/Chaparral: oak more prevalent than brush types. Species include California white oak, California black oak, Oregon white oak, canyon live oak, California live oak.
19. Chaparral/Oak: chaparral-hardwoods in approximately equal proportions. Species similar to 18.
20. Marsh: saltwater marsh. Species include pickleweed.
21. Urban:
22. Area of Little Vegetation: serpentine soil, burned area, limited extent.
23. Bottomland: along river, riparian vegetation present, limited extent.

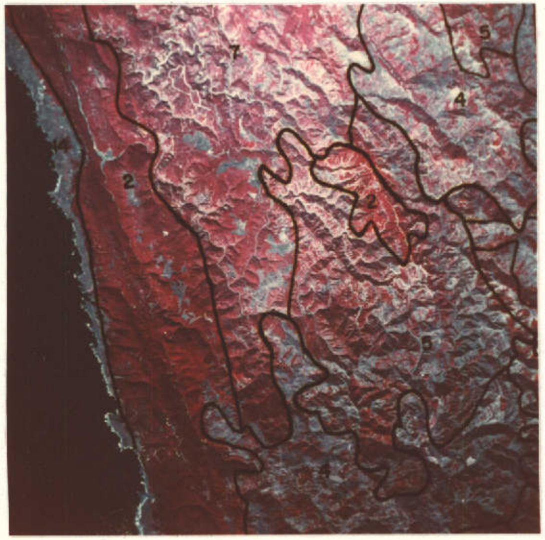
categories: forest, agriculture, grassland and grassland/woodland, chaparral or scrub, marshland, riparian, urban, and barren. As such, they conform to many of the general categories which appear in the classification schemes produced by COAP, ABAG (Association of Bay Area Governments) and the State Parks system. For more accurate or refined vegetation typing, including species identification and determination of land use practices, high resolution imagery, accompanied by some sampling on the ground is essential.

Figure 4.21 shows three examples of the U-2 imagery provided by NASA/Ames. The delineations appearing on these photos are those transferred from the ERTS-1 color composite image by means of the Zoom Transfer Scope. It will be noted that these delineations are easily compared with the actual ground features seen on the U-2 photos and that there is good correlation between the delineations of land use and vegetation/terrain types made from the ERTS-1 color composite image and the features seen on the aerial photos. Accurate identification for the majority of the mapped units, however, was possible only with the aid of the higher resolution aerial photographs. For a few of the mapped units, large scale photographs and ground data were required to provide accurate identification. As can be seen on Figure 4.21-A there is good coincidence between the ERTS-1 and high altitude images for the mapped areas of forest. However, in order to accurately identify the various categories of forest land (types 1-7 in Table 4.19) high resolution images or ground data were required. The sub-categories within the forest class are based mainly on varying proportions of open space and woody vegetation. Forest categories (1-7), however, could not be accurately differentiated from other vegetation types such as riparian (23) and shrub-chaparral (14, 18, 19) on the ERTS-1 composite image.

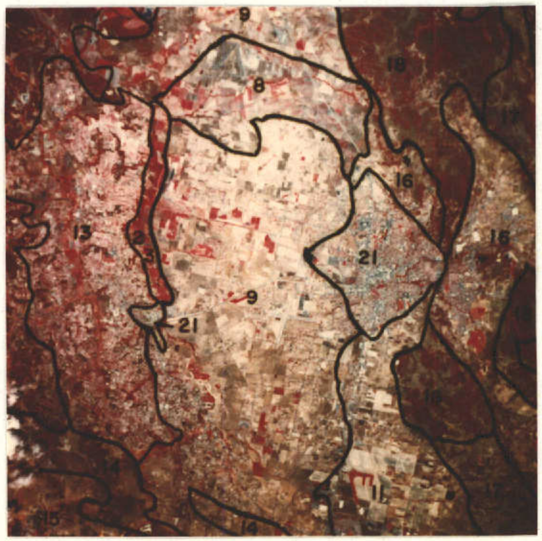
The agricultural categories (8-13), however, could be identified and differentiated from other categories on the ERTS-1 image. A comparison of types 9 and 11 (see Figure 4.21-B, C) suggests that subtle differences between agricultural land categories are related to field size. In addition, the relative amount of irrigated pasture in an agricultural area could be detected on ERTS-1 imagery. The stratification and identification of different agricultural types could be improved by mapping at a more desirable seasonal state using a multidate approach.

In Figure 4.21-C, the transfer of data from ERTS-1 to the U-2 photo shows that grassland and grassland/woodland types can be accurately mapped. Interpretation of the U-2 photo shows that the differences in the ERTS classifications were due to relative density differences in the grassland (15), grassland/oak (16), and brush and oak (17) types. The ERTS-1 image appears to have adequate detail for the differentiation of types 15 and 16. The July seasonal state is excellent for distinguishing grassland, now dry, from healthy, green vegetation types.

Figures 4.21-B and 4.21-C show the capabilities of ERTS-1 for discriminating shrub-chaparral types. While these categories can be



A



B

C

Figure 4.21. These U-2 false-color infrared photographs of Sonoma County illustrate the technique used to evaluate interpretation results derived from ERTS-1 imagery. Delineations and classifications made on the ERTS-1 imagery have been accurately plotted onto the U-2 photographs using a Zoom Transfer Scope. Consequently, boundary placement and type of identification are easily evaluated when positioned on the high definition U-2 photos. Note that photo "A" illustrates mainly forest classifications. Photo "B" shows the cities of Santa Rosa and Petaluma surrounded primarily by agriculture classifications. Additional agricultural classifications surrounded by grassland-shrub-woodland types are illustrated in photo "C". The classification symbols appearing on these photos are explained in Table 4.19.

mapped separately, they tend to be easily confused with forest types. Therefore, higher resolution imagery is required to consistently differentiate these categories.

Marshland (seen on Figure 4.21-C) is easily delineated on the ERTS-1 imagery and can be classified separately from all other categories. Its proximity to the estuary makes the identification of this category possible, although absolute verification is possible only with the aid of U-2 photography.

Several urban centers can be seen on Figures 4.21-B and 4.21-C. The perimeters of the urbanized areas blend into adjoining dry grassland and pasture and are difficult to map accurately on ERTS-1 imagery. The urban centers, however, are visible as separate entities and can be identified as "urban" on the ERTS-1 imagery. The July ERTS-1 imagery is not optimum for classifying urban areas which are bordered by grassland and dry land agriculture. Later in the year these adjoining areas will turn green and will contrast sharply with urban areas on images taken in the red band (e.g., MSS no. 5).

The category of barren areas (22) refers to those areas which appear to be devoid of vegetation or which do not conform in appearance to other natural categories. One example in the nothern part of Sonoma County is a region of serpentine soil which has a sparse covering of vegetation. Another example of barren land is an area in the southern part of the county. It can be seen in Figure 4.21-C and appears to be a brush/oak mixture which was burned by a wildfire sometime after the U-2 imagery was taken on July 7 and before the ERTS-1 imagery was taken on July 27.

The riparian vegetation mapped on Figure 4.21-B occurs along a stream course and though accurately mapped on ERTS-1, it could not be consistently identified in other areas on the ERTS imagery.

Table 4.20 summarizes the findings of the comparative analysis of the ERTS-1 color composite image and the U-2 photography for those categories which were initally mapped on the ERTS-1 color composite image. It should be apparent from this table that many wildland and cultural features (categories) can be accurately delineated on an ERTS-1 image, but only a few can be accurately identified. Most of the mapped categories could be identified using U-2 photography. These analyses also revealed that certain categories could be identified because of their seasonal appearance in July.

4.3.2.3 Vegetation Mapping at Point Reyes National Seashore

The Point Reyes area of Marin County, a 53,000 acre National Seashore since 1962, was selected for investigation of ERTS-1 and high altitude imagery for the following reasons: (1) it is a federally-owned preserve under the management of the National Park Service, (2) it contains representative coastal vegetation types, (approximately half the area is grassland and brush, one-quarter is coniferous forest type,

TABLE 4.20. IDENTIFICATION OF MAPPED UNITS ON ERTS-1 AND LARGER SCALE IMAGERY TAKEN DURING SUMMER SEASONAL STATE.

Categories from Table 1 Delineated on ERTS-1 Color Composite Image	Categories Identifiable on an ERTS-1 Image. (Single Date)	Categories Requiring U-2 or Larger Scale Imagery for Identification
Forest		X
1		X
2		X
3		X
4		X
5		X
6		X
7		X
Agriculture	X	
8		X
9		X
10		X
11		X
12		X
13		X
Grassland & Grassland/ Woodland	X	
15	X	
16	X	
17		X
Shrub-Chaparral		X
14		X
18		X
19		X
Marsh		X
20		X
Urban		
21	X	
Barren		
22		X
Riparian		
23		X

and one-quarter is dunes and cliffs, chaparral and cultivated areas), (3) a vegetation classification scheme considered detailed enough for management was provided by Mr. Dick Brown of the Point Reyes National Seashore, (4) good, synoptic ERTS-1 imagery is available for investigation, (5) excellent high altitude imagery of Point Reyes flown in conjunction with ERTS-1 is available, and (6) an accurate, vegetation type map, delineated and identified from NASA high flight Mission 164 was available.

Procedure

The initial step in the investigation of the ERTS-1 imagery of Point Reyes was to produce color composites (simulated color infrared images) of the area. Through use of the "multiple exposure" technique color infrared composites (transparencies) were created for three dates of ERTS-1 imagery. The three dates are relatively cloud or fog free in three seasons (summer, July 27, 1972; fall, October 25, 1972, and winter, January 5, 1973). It was hypothesized that the phenological differences in plant development would make the delineation and identification of vegetation types more accurate (as depicted on ERTS imagery).

A vegetation type classification scheme appropriate for the management of Point Reyes was provided by the National Park Service. Table 4.21 describes the scheme. Figure 4.22 shows the vegetation type map made from interpretation of NASA high altitude (MX 164) imagery. The categories mapped coincide with those included in the classification scheme described in Table 4.21. On-the-ground observations were made to check the validity of the delineations and identifications that had been made from the high altitude photos.

By means of a photographic enlarger, each ERTS-1 image was magnified to a scale of approximately 1:180,000 and projected onto white background paper. Delineations of homogeneous areas were made on acetate overlays. (See Figure 4.23) Map units were based primarily on color and texture. The vegetation maps produced for each of the three dates of ERTS-1 imagery were made using the same procedure. Each of the map units was then numbered for comparison with the vegetation map prepared from the high altitude U-2 imagery.

A Chi-square analysis was performed to test the hypothesis of independence between the two classification variables, viz. the strata, or ERTS-1 delineations, and the vegetation types as mapped on high altitude imagery. The hypothesis of independence implies that the proportion of land in each vegetation type is constant from stratum to stratum. If there is no independence (a high calculated Chi-square value), there is said to be no interaction. Interaction supposes that the proportion of vegetation types varies between strata, indicating that the delineations on ERTS-1 are meaningful. (A description of the Chi-square technique is given in Section 2.1.2.) To construct the tables necessary for calculating the Chi-square value, the numbered homogeneous areas delineated on ERTS-1 were superimposed on the ground

TABLE 4.21. VEGETATION TYPES IN POINT REYES NATIONAL SEASHORE.

1. Exotic: dominants are primarily exotic species, including eucalyptus, (*Eucalyptus* spp.), Monterey Pine (*Pinus radiata*), Monterey Cypress (*Cupressus macrocarpa*), and brooms (*Cytisus* spp.).

2. Broadleaved evergreen forest: tanoak-madrone forest [tanoak (*Lithocarpus densiflorus*), madrone (*Arbutus menziesii*)], coast live oak (*Quercus agrifolia*), California laurel (*Umbellularia californica*).

3. Broadleaved deciduous forest: Buckeye forest and streambank and lakeshore plants [California buckeye (*Aesculus californica*), alders (*Alnus* spp.), willows (*Salix* spp.), maples (*Acer* spp.), ash (*Fraxinus latifolia*), and dogwood (*Cornus californica*)].

4. Redwood forest: coast redwood (*Sequoia sempervirens*).

5. Douglas fir forest: Douglas fir (*Pseudotsuga menziesii*).

6. Bishop pine forest: dominated by bishop pine (*Pinus muricata*), but also including wax-myrtle (*Myrica californica*), coast live oak, California laurel, and several shrubs.

7. Broadleaved (evergreen) scrub: Chaparral including manzanita (*Arctostaphylos* spp.), ceanothus (*Ceanothus* spp.), huckleberry (*Vaccinium ovatum*), salal (*Gaultheria shallon*), and yerba santa (*Eriodictyon californicum*); coastal brush including coyote brush (*Baccharis pilularis* var. *consanguinea*), coffeeberry (*Rhamnus californica*), blueblossom (*Ceanothus thyrsiflorus*), sticky monkeyflower (*Mimulus aurantiacus*), California sagebrush (*Artemisia californica*), poison oak (*Rhus diversiloba*) and gooseberries (*Ribes* spp.).

8. Grassland: dominated by various species of grasses, both native and exotic.

9. Marshes: both freshwater and saltwater.

10. Dunes and beaches

11. Broadleaved scrub -- broadleaved evergreen forest

12. Bishop pine forest -- broadleaved scrub/grassland

13. Grassland -- broadleaved scrub

14. Douglas fir forest -- broadleaved evergreen forest

15. Grassland -- Douglas fir forest

16. Broadleaved evergreen forest -- chaparral

17. Dunes and beaches -- grassland

18. Broadleaved deciduous forest -- broadleaved evergreen forest

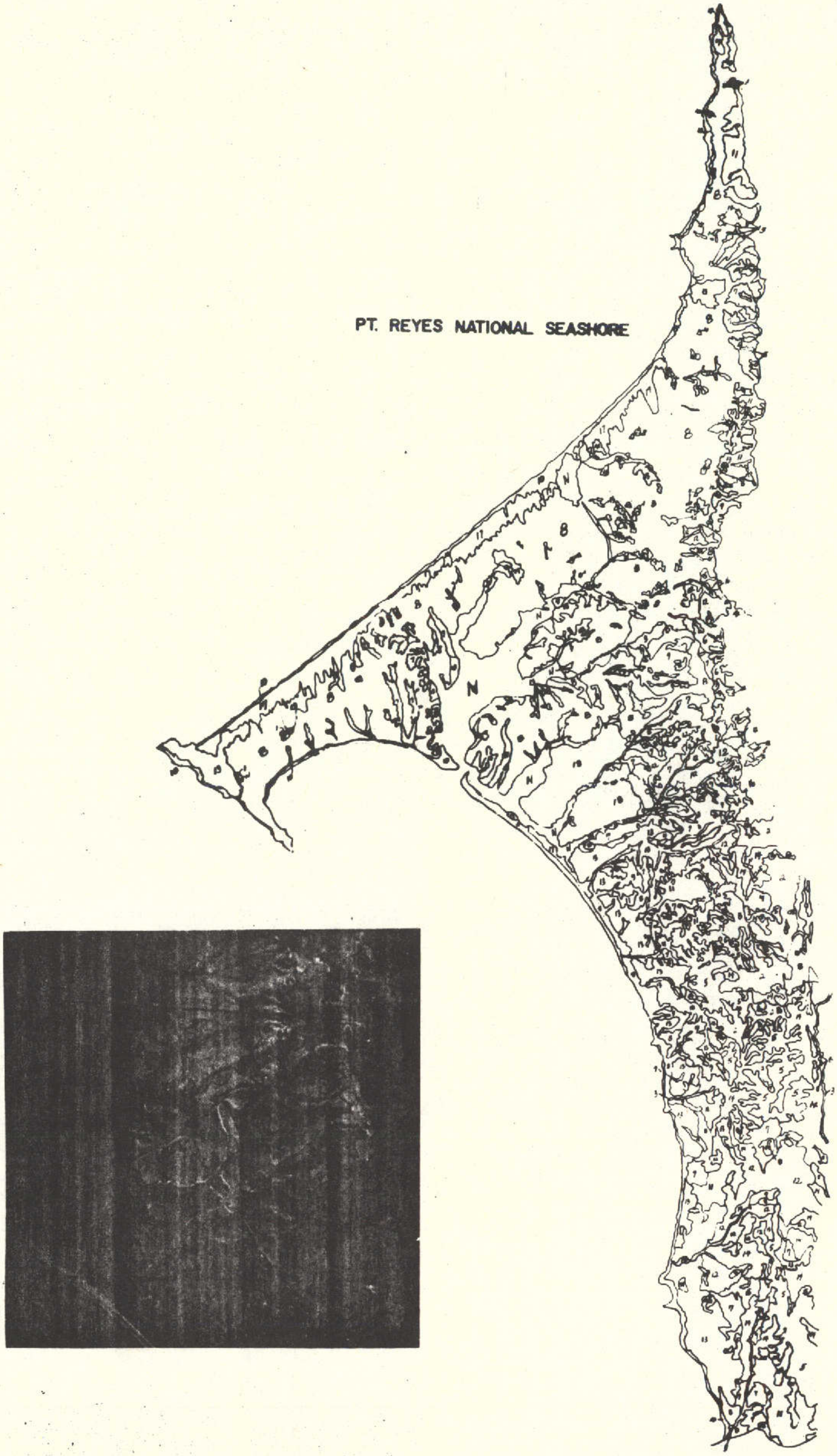
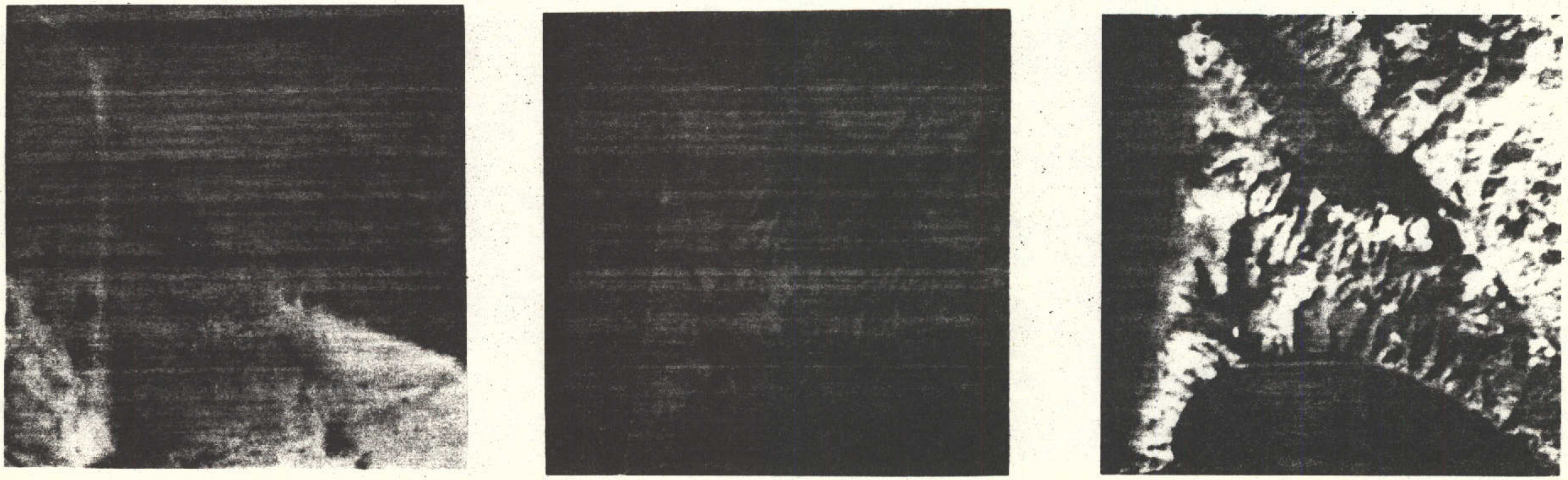


Figure 4.22. Vegetation type map of Pt. Reyes National Seashore classified from NASA high altitude photography (Mission 164). An example of the photography used in preparing the vegetation map is shown in the lower left corner of the figure. The classification scheme and legend identifying the mapped units appears in Table 4.21. This map was used to determine the accuracy of vegetation mapping performed on the ERTS color composites.



July 27, 1972

A

October 10, 1972

B

January 5, 1973

C

Figure 4.23. ERTS-1 color composite images taken on three dates. The overlays on these images show the vegetation mapping performed on the Point Reyes National Seashore.

data map and randomly placed dots ($100/in^2$) were counted to indicate the frequency of ground data points within each ERTS stratum. An example of a portion of the table prepared from the Chi-square analyses can be seen in Table 4.22. As can be noted on this Table, the number of vegetation categories was reduced from eighteen to twelve. This involved combining three coniferous forest types (Redwood, Douglas fir and Bishop pine) into one category; three coniferous forest-chaparral/grassland types (12, 14, 15) into one category), and the elimination of types 16 and 18 which occurred only once on the ground data map.

In these preliminary tests, the calculated Chi-square values for each of the three dates exceeded the theoretical values: July 27, 1972, theoretical Chi-square (.05, 99 d.f.) = 103.87, calculated Chi-square = 12,716.92; October 25, 1972 theoretical Chi-square (.05, 173 d.f.) = 204.69, calculated Chi-square = 23,846.25; January 5, 1973 theoretical Chi-square (.05, 110 d.f.) = 116.24, calculated Chi-square = 16,820.87. Because the number of degrees of freedom associated with each Chi-square value was different, it was not possible to quantitatively compare the three dates of imagery. The differences are attributable to weather patterns on the ERTS-1 images in July and January which obscured areas of Point Reyes National Seashore, and a shift in orbit of the satellite by January 5, causing partial coverage of the test area. However, it was concluded that, based on both the extremely high Chi-square value and the judgement of the interpreter, the October 25 image was the best of the three for delineating the vegetation complex of the area.

Based on this conclusion, further statistical analysis of the October image was carried out. It was felt that the 173 individual strata, as delineated on the ERTS-1 image, would have to be combined to be of use to a land manager. The twelve original categories were reduced to ten ("Marsh" and "Exotic" were eliminated due to the infrequency of occurence) and all strata were then combined into these categories. All strata having five or less observations were excluded from further analysis; it was felt that this was an insufficient number of data points for proper statistical analysis. Each stratum was incorporated into one of the ten categories by comparing the "cell" Chi-square value with the total Chi-square value for the stratum, see Table 4.22. Those strata which had high calculated Chi-square values (Strata 84, 85, 87, 88, and 92) were generally dominated by one vegetation class (grassland, chaparral, broad-leaved evergreen forest-grassland/chaparral, broadleaved evergreen forest, broad-leaved evergreen forest, respectively). Stratum 91 was eliminated due to insufficient observations. The remaining strata, having lower Chi-square values, were composed of more heterogeneous distributions of plant communities. Table 4.23 shows the results of the Chi-square analyses performed on the refined data from the October 25, 1972 ERTS-1 image. The high Chi-square values associated with each stratum indicate that there was interaction between the stratum and the corresponding land use categories and that the predominant vegetation type is unique for each stratum. It can be concluded from this test that the boundaries delineated on ERTS-1 are legitimate for the vegetation-type categories defined.

TABLE 4.22

		STRATUM 84	STRATUM 85	STRATUM 86	STRATUM 87	STRATUM 88	STRATUM 89	STRATUM 90	STRATUM 91	STRATUM 92
A	BL EG FOREST	0	0	0	0	12	0	0	0	85
	EXPECTED	3.724	2.534	1.497	2.380	.461	.461	.921	.192	5.145
	CHI SQ	3.724	2.534	1.497	2.380	289.011	.461	.921	.192	1239.484
B	BL DC FOREST	0	0	0	0	0	0	0	0	0
	EXPECTED	.478	.325	.192	.306	.059	.059	.118	.025	.661
	CHI SQ	.478	.325	.192	.306	.059	.059	.118	.025	.661
C	CONIFEROUS FOREST	0	0	3	10	0	0	7	4	43
	EXPECTED	4.783	3.255	1.923	3.057	.592	.592	1.184	.247	6.608
	CHI SQ	4.783	3.255	.603	15.765	.592	.592	28.586	57.138	200.422
D	CHAPARRAL	1	0	0	16	0	0	0	0	0
	EXPECTED	8.490	5.777	3.414	5.427	1.050	1.050	2.101	.438	11.729
	CHI SQ	6.608	5.777	3.414	20.599	1.050	1.050	2.101	.438	11.729
E	GRASSLAND	26	0	20	2	0	4	0	0	2
	EXPECTED	46.604	31.710	18.738	29.788	5.765	5.765	11.531	2.402	64.380
	CHI SQ	9.109	31.710	.085	25.922	5.765	.541	11.531	2.402	60.443
F	MARSH	0	0	0	0	0	0	0	0	0
	EXPECTED	.068	.046	.027	.044	.008	.008	.017	.004	.094
	CHI SQ	.068	.046	.027	.044	.008	.008	.017	.004	.094
G	DUNES * BEACHES	0	0	0	0	0	0	0	0	0
	EXPECTED	2.597	1.767	1.044	1.660	.321	.321	.642	.134	3.587
	CHI SQ	2.597	1.767	1.044	1.660	.321	.321	.642	.134	3.587
H	GRASSLD * CHAPL	70	12	0	3	0	8	14	0	0
	EXPECTED	15.187	10.334	6.106	9.707	1.879	1.879	3.758	.783	20.980
	CHI SQ	197.827	.269	6.106	4.634	1.879	19.943	27.918	.783	20.980
I	GRASSLD * DUNES	0	0	0	0	0	0	0	0	0
	EXPECTED	4.766	3.243	1.916	3.046	.590	.590	1.179	.246	6.584
	CHI SQ	4.766	3.243	1.916	3.046	.590	.590	1.179	.246	6.584
J	C. FOR * GRLD/CH	0	0	16	4	0	0	3	1	4
	EXPECTED	6.919	4.708	2.782	4.422	.856	.856	1.712	.357	9.558
	CHI SQ	6.919	4.708	62.809	.040	.856	.856	.969	1.161	3.232
K	BL EG FOR * GR/CH	0	54	0	27	0	0	0	0	0
	EXPECTED	3.092	2.104	1.243	1.976	.383	.383	.765	.159	4.272
	CHI SQ	3.092	1280.095	1.243	316.829	.383	.383	.765	.159	4.272
L	EXOTIC	0	0	0	0	0	0	0	0	0
	EXPECTED	.290	.198	.117	.186	.036	.036	.072	.015	.401
	CHI SQ	.290	.198	.117	.186	.036	.036	.072	.015	.401
	COLUMN SUMS	97	66	39	62	12	12	24	5	134
	COL CHI SUMS	240.263	1333.926	79.054	391.412	300.550	24.839	74.820	62.695	1551.889

An example of a portion of the table used for the Chi-square analysis of Point Reyes. Three such tables were prepared; one for each date of ERTS-1 imagery interpreted. The text explains how the strata were combined for the additional analysis done on the October 25 image.

TABLE 4.23. CONTINGENCY TABLE OF χ^2 VALUES AND VEGETATION TYPE CATEGORY FREQUENCY BY STRATA.*
(POINT REYES NATIONAL SEASHORE, OCTOBER 25, 1972, ERTS-1.)

Category	Stratum	Broadleaved Evergreen Forest	Broadleaved Deciduous Forest	Coniferous Forest	Chaparral	Grassland	Dunes and Beaches	Grassland/ Chaparral	Grassland/ Dunes	Coniferous Forest- Grassland/ Chaparral	Broadleaved Evergreen Forest- Grassland/ Chaparral	Total
Broadleaved Evergreen Forest	Observed	37.	0.	0.	0.	0.	0.	1.	0.	24.	99.	161.
	Chi-square	767.032	.708	2.616	2.462	54.005	1.354	36.214	12.093	3.321	557.630	1437.436
Broadleaved Deciduous Forest	Observed	0	16	0	5	2	0	0	0	8	1	32
	Chi-square	.324	1787.967	.520	41.583	7.107	.269	7.590	2.404	.174	1.005	1848.942
Coniferous Forest	Observed	7	0	59	0	0	0	0	0	140	39	245
	Chi-square	8.225	1.077	760.535	3.746	82.182	2.060	58.113	18.403	143.603	17.802	1095.746
Chaparral	Observed	2	0	17	71	32	0	189	5	111	20	447
	Chi-square	1.411	1.965	13.058	602.377	92.769	3.759	64.934	24.321	2.193	7.565	814.353
Grassland	Observed	4	1	0	3	1569	0	348	102	69	32	2128
	Chi-square	14.299	7.462	34.572	26.815	1024.582	17.896	48.678	20.932	331.564	116.355	1643.155
Dunes and Beaches	Observed	0	0	0	0	25	40	44	61	0	0	170
	Chi-square	1.722	.747	2.762	2.599	17.984	1040.574	.335	182.167	36.684	13.939	1299.515
Grassland/Chaparral	Observed	0	0	0	1	84	0	625	17	99	51	877
	Chi-square	8.884	3.855	14.248	11.484	150.163	7.375	835.850	36.263	43.035	6.080	1117.238
Grassland/Dunes	Observed	0	0	0	0	33	4	17	197	0	0	251
	Chi-square	2.543	1.103	4.078	3.828	31.129	1.691	30.390	1683.273	54.163	20.581	1832.788
Coniferous Forest-Grassland/Chaparral	Observed	2	6	9	0	3	0	12	0	639	55	726
	Chi-square	3.898	2.471	.622	11.101	237.563	6.106	149.039	54.533	1485.049	.345	1950.767
Broadleaved Evergreen Forest-Grassland/Chaparral	Observed	1	0	0	0	7	0	5	11	39	132	195
	Chi-square	.482	.857	3.168	2.982	52.159	1.640	36.793	.908	.225	841.731	940.945
Total	Observed	53	23	85	80	1755	44	1241	393	1129	429	5232
	Chi-square	808.820	1808.213	836.218	708.987	1749.643	1082.724	1267.938	2035.298	2100.010	1583.034	13,980.89

Theoretical Chi-square (.05, 81 d.f.) = 102.70
Calculated Chi-square = 13,980.89

*Note that the overall calculated χ^2 exceeds the theoretical value, thus implying that the distribution of vegetation type categories varies with stratum.

Based upon Chi-square analyses of ERTS images dated July, October, and January, and the evaluations by the interpreter, it is felt that accurate delineation of the vegetation types proposed by the National Park Service personnel at Point Reyes is possible on any of the three dates of ERTS-1 imagery examined. The October 25, 1972 image is indicated as the most preferable due to its highest Chi-square value. The vegetation units on this image were more easily discriminated, partially due to phenological changes associated with the fall seasonal state: e.g., the deciduous trees were defoliating at that time and therefore reflecting less infrared than either broadleaved evergreen or coniferous trees. In addition the greening of the grassland areas after the first rains gave a bright infrared reflectance and made differentiation from the less reflective chaparral/grassland and pure grassland types more apparent. Furthermore, there was greater contrast in the forested areas on the October image.

In summary, Sonoma County and Point Reyes National Seashore were studied in the context of analyzing ERTS-1 and high altitude aircraft imagery to determine the environmental or land use parameters that can be delineated and classified on ERTS-1 imagery to determine to what degree identification of these areas is possible on ERTS-1 imagery alone and with the aid of supporting aircraft and ground data. In both qualitative and quantitative analyses it was found that accurate delineation and classification of vegetation types is possible on ERTS-1 imagery, even in areas as complex as these. While identification of certain gross vegetation types (i.e., agriculture, grassland, urban and forest) is possible on ERTS-1 imagery alone, given appropriate knowledge of season of year, climatic regime and vegetation systems as well as proper date of ERTS-1 imagery, more refined identification of complex types is possible only with the aid of proper supporting aerial imagery and on-the-ground observation.

4.3.3 The Northern Study Site of the North Coast Test Site

4.3.3.1 Introduction

Remote sensing investigations in the northern study site have focused on the Redwood Creek basin lying to the north and east of Eureka, California. This area is of special interest to administrators of Redwood National Park because the southern portion of the Park occupies a downstream segment of this basin. In order to locate, identify, and monitor resource types and processes within the Redwood Creek watershed that affect the condition of this important area of the Park, a cooperative agreement between the Center for Remote Sensing Research and the National Park Service has been formulated.

The major objectives of the CRSR-NPS Cooperative agreement are to:

1. Demonstrate the utility of ERTS-1 imagery to provide information for planning and management purposes within the Park.

2. Demonstrate the usefulness of high altitude platform imagery for preparing inventories of resources and monitoring changes in the resource base.

3. Determine the extent to which aircraft or space imagery can locate present and potential problem areas.

4. Determine the specifications for a practical remote sensing system designed to assist in resolving the Park Service's resource management problems.

The cooperative CRSR-NPS Redwood National Park Study also includes these specific objective outputs:

1. Establish continuous ecosystem monitoring sites.

2. Construct an historical record of change within specified areas over the past thirty years using appropriate imagery.

3. Compare relevant types of resource management information extractable from different dates and types of imagery.

4. Compare the amount of detail resolvable from the various types and scales of imagery to define data formats for evaluating various resource management problems.

5. Make cost, time and accuracy comparisons for the imagery sets examined in points (3) and (4) above.

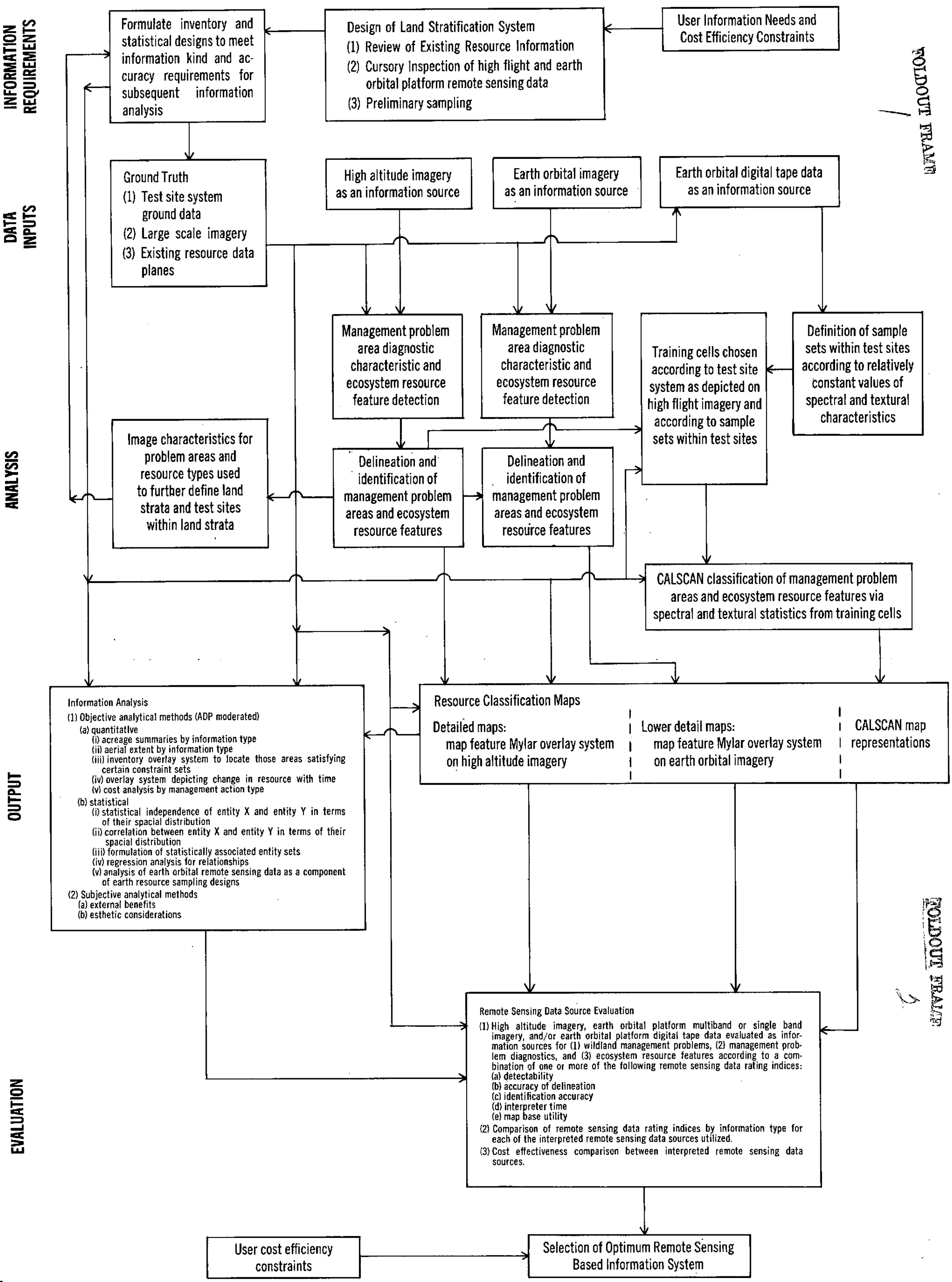
6. Prepare a map set of resource features within and adjacent to specified portions of the Redwood National Park using high altitude platform imagery.

7. Using ERTS-1 and supporting aircraft remote sensing data, monitor the changes which can be observed and determine their significance to the evaluation of present and potential resource management problems.

8. List all image parameters which can be used to detect, identify, infer or evaluate present and potential management problems (e.g., specific features, tone or color signatures, patterns, etc.)

Format

A constructive framework or format to achieve the specific objectives of the cooperative agreement is outlined in the left-hand column of Table 4.24. This applications format is based upon the development of two general remote sensing capabilities. The first is the identification of present and potential problem areas within and adjacent to the Park. This capability could be extremely helpful in protecting Park resources as well as in minimizing private landowner management costs. The second capability is designed to aid in the inventory and analysis of ecosystems



FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 4.24. The remote sensing based information system.

and landscape units within Redwood National Park. This resource information can be used to prepare environmental impact statements and to formulate the Redwood National Park Master Plan.

As will be discussed in a later section, it is also the intent of this study to develop remote sensing techniques and optimum imagery combinations that are applicable for examining resource types, resource parameters, and resource problems throughout the California north coastal region. The "format" therefore recognizes the large spectrum of regional resource entities and processes which are characteristic of the Redwood Creek basin. Resource feature characteristics may be modified somewhat from subregion to subregion to account for variations in flora, geology and land use practice. Hence the approach is one of defining diagnostic characteristics of resource problems and then developing a general purpose, state-of-the-art, remote sensing based tool with which to analyze resource problems.

Approach to Analysis: The Information System

The remote sensing acquisition and analysis system to be utilized in the CRSR-NPS Redwood National Park cooperative study is conceptualized in Figure 4.24. It provides a structure for the optimum integration of various remote sensing techniques, imagery types, ground data types, and supplementary data. The system provides a framework for assessing the relative ability of remote sensing techniques to detect, identify, and evaluate management problem areas and/or resource types. This system also provides for an analysis of relative time, cost and accuracy.

Figure 4.24 also indicates information analysis functions to be performed by automatic data processing subsystems. These functions consist of quantitative and statistical analytical procedures that supplement manual interpretations.

The Data Base

The U-2 photos analyzed for this report were taken on October 6, 1972 and April 4, 1973. The October photographs were taken with color-infrared film from an altitude of 65,000 feet and at a scale of 1:125,000. The April photographs were also taken from an altitude of 65,000 feet with color-infrared film but at two different scales, namely 1:125,000 and 1:31,750. The U-2 photos taken at an original scale of 1:125,000 were enlarged approximately three and one-half times to a map base scale of 1:37,500. The U-2 photos taken at an original scale of 1:31,750 were enlarged two times to a map base scale of 1:15,875. The enlarged U-2 photos acted both as a base for interpreted information and as a base for displaying existing resource information of the imaged area.

The ERTS-1 images analyzed for this report were taken on October 27, 1972 and on March 2 and April 6, 1973. All images were available at an original scale of 1:1,000,000. The ERTS-1 images were enlarged to a common map base scale of 1:125,000, and used as a workable land use/land

type map base.

The diagnostic features and resource descriptors listed in Table 4.24 were obtained by examination of ground data, by a review of relationships defined in the physical, biological, and earth sciences, and by conversations with personnel from the National Park Service, private industry, and various research organizations.*

Where image types do not adequately define resource problems and parameters of importance, supplementary information can be acquired from existing sources. For instance, planimetric control and geologic bedrock information may be obtained from U.S. Geological Survey publications. Soil phase characterization is available from outputs of the California Cooperative Soil-Vegetation Survey. In this manner remote sensing information may be combined with existing knowledge to provide a more efficient resource identification and evaluation system.

Our evaluation of U-2 and ERTS-1 imagery as information sources and as map bases has been summarized in Table 4.24. Management problems and their associated diagnostic characteristics have been rated according to their relative degree of detectability. ("Detection" implies the ability to segregate from the surrounding image matrix a specific, identifiable feature.) Based on a weighted evaluation of the degree of detectability for relevant diagnostic characteristics, each management problem is assigned a relative (a) detectability, (b) accuracy of delineation, (c) identification, (d) interpreter time, and (e) map base utility value for each image type. "Accuracy of delineation" is a measure of the relative ability to locate the boundary for a given entity. "Identification" describes the accuracy with which a given management problem or resource feature is identified and/or characterized. The time rating evaluates interpreter time for the detection, delineation and identification task.

Map base utility is defined as the relative ability of an image to serve as a base upon which to record legible resource feature delineations and associated symbolic legends. This utility for a given resource type or resource characteristic is a function of three factors. First is the number of class intervals for the given resource parameter (e.g., the number of class intervals of soil depth or the number of vegetation type classes). The second factor is the scale of the photo serving as a map base. The smaller the scale the less legible will be the map. Finally the variability of the resource type or characteristic over the area represented by the image must be considered. If the given resource characteristic is quite variable over short distances and the

* In this regard, CRSR wishes to thank Dr. Richard Janda and Mr. Steve Colman of the U.S. Geological Survey for their information concerning mass soil movement interpretation techniques. Grateful acknowledgement is also extended to Mr. Ted Hatzimanolis, Resource Management Specialist of Redwood National Park, for his helpful characterization of resource types and ecological processes in the Redwood region.

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investigator has selected a large number of class intervals then the map may become unreadable. To develop a more legible map base in this instance, either the number of class intervals must be reduced or the scale of the image must be increased. Map base utility ratings given in Tables 4.24, 4.25, and 4.26 were based on the assumption of a workable and meaningful number of class intervals and then judged on the resource feature's variability over space relative to the scale of the image.

Resource features useful in chracterizing Park ecosystems and landscape units have been rated as to their image detectability and ability to be portrayed on the image in map form.

4.3.3.2 Analysis of Management Problems and Resource Factors in the Redwood Creek Basin

Evaluation of information source and map base capabilities for the imagery sets listed in Table 4.24 may proceed by analysis of the general ratings given for management problems and resource features.

Management Problem Areas

The major relationship evident in Table 4.24 is that ERTS-1 imagery is generally not useful, or only marginally useful, for detection of present and potential management problem areas in the northern study site. This is partly due to the relatively large resolution element size of the ERTS-1 system. Nevertheless, this result applies only to manually interpreted ERTS-1 images. Preliminary analysis of ERTS-1 magnetic tapes indicates a significant improvement for recognition of features indicative of management problems.

The utility of ERTS-1 imagery as a map base at a scale of 1:125,000 is limited. Only in regard to the analysis of potential harvesting techniques for a given location does its usefulness as a map base appear operationally feasible. Analysis of potential harvesting methods involves the investigation of factors given in Table 4.24 that influence the decision to use tractor or cable logging and the type of forest regeneration method to be employed. Enlargement of the ERTS-1 imagery to scales larger than 1:125,000 may not prove to be cost efficient.

Table 4.24 indicates that high altitude U-2 imagery is generally very useful in the detection, delineation, and identification of resource management problems. All three U-2 image types analyzed are especially useful in the examination of (1) presently active soil mass movement areas in prairie and forest, (2) detection of present and potential locations of bank undercutting via stream action, and (3) analysis of potential harvesting techniques for a given location. In these cases the 1:15,875 U-2 image (original scale 1:31,750) has a general problem detectability rating at least one class above that for the 1:37,500

TABLE 4.25. TENTATIVE ASSESSMENT OF THE RELATIVE ABILITY OF DIFFERENT IMAGE SOURCES TO PROVIDE INFORMATION ON FOREST HARVEST.[1]

Imagery Parameters[2]								
Vehicle	High Alt U-2	High Alt U-2	High Alt U-2	ERTS-1	ERTS-1	ERTS-1	ERTS-1	ERTS-1
Sensor System	RC-10	A-1	A-1	MSS 4/5/7	MSS 4/5/7	MSS 4/5/7	MSS Band 5	MSS Band 7
Mission Date	10-6-72	4-4-73	4-4-73	10-27-72	3-2-73	4-6-73	4-6-73	4-6-73
Interpreted Image Format	1:37,500	1:37,500	1:15,875	1:125,000	1:125,000	1:125,000	1:125,000	1:125,000
Forest Harvest Characteristics								
I. Harvest Method to Approximately Eleven Years Ago								
A. Tractor	D4 A4 I3 M4	D4 A4 I3 M4	D4 A4 I4 M4	N	N	N	N	N
B. Cable	D4 A3 I3 M4	D4 A3 I3 M4	D4 A4 I4 M4	N	N	N	N	N
C. Tractor or Cable	---	---	---	D2-D3 A2-A3 I3-I4 M2-M3	D3 A2-A3 I2-I4 M2-M3	D3-D4 A3 I3-I4 M2-M3	D3 A2 I3 M2-M3	D1 A1 I1 M2-M3
II. Regeneration Method								
A. Selective (0-70 percent of the commercial volume removed)	I3	I3	I4	I1	I1	I1	I1	N
B. Seed Tree (approximately six seed trees left per acre	I2	I2-I3	I3	I1	I1	I1	I1	N
C. Clear or Clean Cut (generally Redwood coppice [sprout]; Douglas-fir artificially seeded)	I3	I3	I4	I2	I2	I2	I2	N
III. Time Since Harvest								
A. Present to five years ago	I4	I4	I4	I4	I4	I4	I3	I1
B. Six to seven years ago	I2	I2	I2	N	N	N	N	N
C. Six to eleven years ago	I4	I4	I4	I3	I2	I3	I3	I1
D. Twelve to approximately seventeen years ago	I3-I4	I3-I4	I3-I4	I2	I2	I2	I1	I2
E. Approximately seventeen years and more	I2	I2	I2	I2	I2	I2	I1	I1

Footnote 1: Legend for image rating indices is that given in Table 4.24.

Footnote 2: For other parameters see Table 4.24.

TABLE 4.26. TENTATIVE ASSESSMENT OF THE RELATIVE ABILITY OF SELECTED ERTS-1 IMAGE SOURCES TO PROVIDE INFORMATION ON SNOW PACK AND SEDIMENT PLUMES.[1]

Imagery Parameters[2]				
Sensor System	MSS 4/5/7 Col. IR Comp	MSS 4/5/7 Col. IR Comp	MSS Band 5	MSS Band 7
Mission Date	3-2-73	4-6-73	4-6-73	4-6-73
Interpreted Image Format	1:125,000	1:125,000	1:125,000	1:125,000
Snow Pack	D4 A4 i4 T4 M3-M4	D4 A4 i4 T4 M3-M4	D4 A3 i2 T4 M3-M4	D3 A2 i3 T2 M3-M4
River Sediment Plume Near Ocean Outlet	D4 A4 i4 T4 M4	D3 A3 i3 T3 M4	D3 A3 i3 T3 M4	Not visible

Footnote 1: Legend for image rating indices is that given in Table 4.24.

Footnote 2: For other parameters see Table 4.24.

images (original scale 1:125,000).

The larger scale 1:15,875 U-2 image was more useful than the 1:37,500 U-2 imagery for detection, delineation, and identification of (1) potential soil mass movement areas and (2) potential road failure locations.

The October, 1972 U-2 image appears to be a better information source than the analog April, 1973 image in the analysis of presently active soil movement and in prairies and forest vegetation types. This conclusion is based upon the higher rating of October U-2 photos for management problem detectability, accuracy of delineation, and identification despite the fact that less interpreter time was required using April U-2 photos. The increased detectability of hummocky (slide-prone) prairie microrelief and the higher ability to differentiate red alder from the surrounding forest matrix on the October photograph contributed to this situation.

A similar result exists for the detection of bank undercutting problem areas. Accurate location and identification of stream axis direction and streambank areas that are subject to the highest potential stream-caused erosion are facilitated by the low water levels seen on the October photography. The low flow periods of summer and fall in the north coast region appear to be the optimal times for detecting areas where stream bank undercutting could occur. Based upon early detection of such areas, measures such as channel dredging or stream bank stabilization could be taken to protect streamside redwood forests from winter floods. The U-2 (1:37,500) image types supply useful stream bank undercutting information only on large streams such as Redwood Creek. Detailed information concerning small tributaries along Redwood Creek must be obtained from the larger scale U-2 imagery.

The U-2 image (1:37,500) taken in April, 1973 was more useful than its October U-2 counterpart for detecting prairies in which soil movement is a potential threat. During the spring areas with deeper soil and therefore greater water storage capacity will support actively metabolizing grassland vegetation for a longer period than areas having shallower soil. If soil depth is quite variable over a relatively small area, a mottled pinkish (live herbage dominant) versus yellowish (dead or nearly dead herbage) coloration can be detected. These patterns are believed by some geologists to indicate potential soil mass movement locations in prairies.

The early detection of soil movement in both prairie and forest could allow immediate stabilization action to be recommended or initiated by the land manager. Remedial action might consist of upslope hydrologic regime modification to decrease slide initiating water inputs, vegetation manipulation to stabilize soil surrounding slide-prone areas, and slide toe stablization. Characterization of existing slide activity may aid in the detection of potential slides in non-active areas. Detection of potential soil mass movement locations is necessary in

developing specifications for road and trail design and location. Such detection is also important for determining the types of vegetation manipulation possible without adverse environmental impact.

The U-2 photography (1:15,875) taken in April appears to be the best image type for use as a detailed management problem and general resource feature map base. This conclusion was the consensus of private wood products firms and government agencies that have reviewed the above image types. However, the 1:37,500 U-2 image types were suitable as map bases for displaying (a) resource features and (b) the following management problem areas: present and potential prairie soil movement locations, areas requiring harvesting technique analysis, and forest restocking problem locations. Additionally, the 1:37,500 U-2 image types (1) is more cost efficient on a per acre basis than the 1:15,875 type (see top of Table 4.24) and (2) covers nearly an order of magnitude greater area. Therefore, preliminary indications are that private firms and government organizations contacted to date by CRSR intend to use both U-2 image formats (original photo scales: 1:125,000 and 1:31,750).

Resource Features Useful in Characterization of Ecosystems and Landscape Units

Reference to Table 4.24 indicates that ERTS-1 imagery can be useful for detecting several ecosystem parameters, particularly topographic position, general slope class, and land use pattern. In conjunction with land use data (generally harvest type and date), ERTS-1 color composites can sometimes be used to indicate broad values of vegetation type, stand class density, and rate of plant successional change on disturbed sites. For example, ERTS-1 bands (except band 7) can be used to clearly differentiate old growth redwood forest from young growth stands.

Band 7 (ERTS), however, is very useful for obtaining information on stratigraphic units via interpretation of land form characteristics. Diagnostic features of geologic formations utilized on band 7 include drainage patterns, ridge linearity, slope class, and potential locations of fault and shear zones.

Bays, lagoons, and large stream channels (e.g., the Klamath River, the downstream portion of Redwood Creek) can also be identified on the ERTS-1 color composites and on band 7. However, small water storage ponds and secondary and/or small primary stream courses either cannot be identified or are at best very difficult to identify.

The utility of ERTS-1 image formats as a map base for overlay of resource feature information ranged from "poor" in the case of soil movement activity to "excellent" for stratigraphic unit type. Broad vegetation type and land use in the Redwood Region appear to be other parameters potentially mappable on 1:125,000 ERTS-1 enlargements.

Table 4.24 indicates that all three U-2 imagery formats were useful information sources for detecting and identifying the majority of ecosystem resource features. The U-2 photo enlarged to a scale of 1:15,875 was often rated at one detectability class above the 1:37,500 formats. However, the U-2 imagery could not provide exact information on species composition and slope class. The latter feature is a good example of a factor which could be quantified more precisely utilizing stereo interpretation techniques.

Note the extremely good ability of U-2 imagery to define the location and kind of road networks compared to ERTS-1 image types. The characteristics of little-used secondary and spur roads are most evident on the U-2 1:15,875 imagery.

4.3.3.3 Analysis of Forest Harvesting Activities and Other Resource Features Which Change with Time

Forest Harvesting Practices

Useful information characterizing forest harvest activities in the north coast study site can be obtained from high altitude and earth orbital imagery. This information can be used for the establishment of vegetation interpretation keys, assessment of tree stocking levels, measurement of successional change, establishment of vegetation density indices, mapping of land use pattern, and for a base line to record subsequent erosion and revegetation problems. The reader will recognize these items as necessary inputs to the investigation of management problem areas and definition of ecosystem units.

Table 4.25 evaluates the relative ability of each image type to characterize forest harvest. The analysis is composed of three parts. First each image type is rated according to the interpreter's ability to detect, accurately delineate, and identify a given timber harvest system. Each image type is also rated according to its usefulness as a map base.

The second portion of the analysis involves the identification of the regeneration method used in a harvested area. The third step in the analysis involves evaluation of the time interval since an area was harvested. Black-and-white panchromatic aerial photos (scale 1:12,000 to 1:15,000) taken in 1936, 1962, 1966, 1968 and 1972 were available for reconstructing much of the harvesting history in the Redwood Creek basin.

The April ERTS-1 color composite imagery was found to be a reliable information source from which to consistently detect and identify areas harvested in the Redwood Creek region in the last eleven years. The October ERTS-1 composite, however, did not allow differentiation of dormant "prairies" (natural perennial grassland areas) from recently harvested areas due to similar reflectance characteristics. This was

not a problem in April when the prairie vegetation was metabolically active.

Interpreters had difficulty with the October ERTS composite in distinguishing between areas harvested six to eleven years ago and those harvested eleven or more years ago. Interpreters experienced similar difficulty on the March ERTS color composite but here the harvested areas six to eleven years old were sometimes confused with old growth stands, especially on northern exposures. The April 1973, and to a somewhat lesser extent the October 1972, ERTS color composites, appeared to allow the highest interpreter success in differentiating harvested areas which are older than eleven years.

The April ERTS image (band 5) was generally useful for detecting areas harvested within the past eleven years. However, harvest period image ratings are generally one class below those of the April 1973 color composite. An exception is the six to eleven year old period, but, even here, increased difficulty in differentiation from other harvest categories is evident. Analysis of October 27, 1972 band 5 ERTS-1 coverage gives similar results. Band 7 is generally not useful as a source of forest harvest information.

It should be noted that the method of harvest was not identifiable on any of the ERTS-1 image types examined. Moreover, it was difficult to differentiate regeneration methods. The clear or clean harvest regeneration system was the most recognizable method.

U-2 image types allowed very acceptable interpreter success in harvest method identification, differentiation between selective and clear cut regeneration methods, and identification of time of harvest to approximately seventeen years ago. It became increasingly more difficult to determine the age of stands that had been harvested more than seventeen years ago because (1) it was difficult to distinguish older harvested areas from old burned area and (2) the regeneration (new crop of trees) had formed a crown canopy of one hundred percent, thus obscuring the evidence of previous harvesting activity.

The 1:15,875 U-2 image type received the highest evaluation ratings for the making of harvest method and regeneration system analyses. The seed tree regeneration method was difficult to identify with all U-2 image types because there is little apparent difference between a recently clear cut area and a seed tree area in the Redwood Region for minimum object resolutions of five to twenty feet.

All U-2 imagery types listed in Table 4.25 appeared to have high utility as map bases for forest-harvest information. The 1:15,875 scale U-2 photo enlargements are preferred, however, because they show greater detail regarding skid roads, residual material remaining after harvesting, etc. ERTS-1 1:125,000 enlargements provide a good map base for showing location and extent of harvested areas but are not detailed enough to show residual material, roads, amount of surface

disturbance, etc.

Other Resource Features

Other resource features readily detectable and characterizable on ERTS-1 imagery and of importance in hydrologic analysis are listed in Table 4.26. They include river sediment plumes and snow pack. The former may be related to determination of river sediment load and discharge rate, while the latter can be related to water runoff studies.

Table 4.26 indicates that both the March 1973 and the April 1973 ERTS-1 color composites were excellent in showing the distribution and extent of snow pack. The former ERTS image appears to be the best for displaying sediment plumes. This may be in part due to the lower stream discharge in April as compared to March. The possible correlation between discharge and size of sediment plume could be developed into a useful function for the analysis of stream sediment load.

Single band black-and-white ERTS-1 images are less useful for the study of snow pack and sediment plumes. The snow pack identification rating for band 5 is low because it is difficult to differentiate the snow pack from medium altitude cloud formations. Snow pack can be differentiated from clouds on MSS band 7 because cloud shadows are conspicuous, but the time and accuracy of interpretation are not at favorable as on band 5. Band 7 is not useful for sediment plume detection.

The U-2 image types were not examined with respect to snow pack or sediment plume features. However, preliminary analysis of April 1973 U-2 transparencies within the northern study site where these resource features were evident indicates the following. Detection, accuracy of delineation, and identification ratings for snow pack extent appear to be excellent in the absence of cloud cover. Image ratings for sediment plume extent are more moderate, especially in ocean sections somewhat removed from river outlets.

Monitoring of Change Over Time

The extent to which changes in a wildland area can be monitored on ERTS or U-2 images is a function of the relative ability to detect management problems, diagnostic parameters, or resource features at different dates of the year.

The ERTS-1 color composites examined in this study appear to be useful for monitoring seasonal changes (phenological) in vegetation. Over longer periods of time they should be useful in monitoring stand density, rate of successional change over time, and changes in water level in marshland. More specific information may be monitored from the ERTS composites regarding change in land use pattern, location and extent of recent forest harvesting activities, and snow pack and river sediment plume location.

ERTS-1 band 5 appears to be most useful in monitoring change in land use pattern, location and extent of recent forest harvesting activity, snow pack location, and detection of sediment plume activity. Band 7 is marginally useful for detection of change in large to medium size water body extent and snow pack location.

The 1:15,875 scale U-2 image type is an appropriate format for monitoring soil movement in prairie and forest types, stream channel axis shift, bank undercutting, and erosion and revegetation history necessary for forest harvest technique analysis. Additionally this format could be very effective for monitoring changes in seasonal vegetation type, long term vegetation type, stand structure and density, rate of plant succession, water resource modification (e.g. change in emergency water ponds), land use pattern, road network, and harvest and regeneration methods. The U-2 1:37,500 image formats are also dependable information monitoring sources; however, the interpretations are not as detailed because of slightly lower image resolution.

4.3.3.4 Application of U-2 and ERTS-1 Imagery as Information Sources and as Map Bases

Specific applications for high altitude and earth orbital imagery in the northern study site of the California North Coast Test Site have been discussed earlier in this section. Moreover, user applications are implied in the specific objectives of the cooperative CRSR-NPS Redwood National Park study and the resource analysis format given in Table 4.24.

To demonstrate the manner in which the image types examined in this study can be used singly and in combination as a source of interpretative information, as a format for monitoring resource change, and as a map base, reference should be made to the photo examples and captions in Figures 4.25 through 4.31.

4.3.3.5 Conclusion

The Redwood Creek basin is a biological and geological microcosm of a much larger area of California's north coast region. It is therefore intended that the remote sensing techniques utilized in this study be applied as management tools by private as well as public wildland resource management organizations throughout this section of the state. The improvement in acquisition time and in the type and amount of resource information provided by state-of-the-art remote sensing should contribute substantially to a more enlightened level of land husbandry in the California north coast area.

In this regard, several private wood products firms with relatively large land holdings in the northern study site have been briefed on the project progress. These firms include Simpson Timber Company, Arcata Redwood Company, Louisiana Pacific Corporation, and Rellim Redwood

Figure 4.25: (see next page)

Figure 4.25. The 1:37,500 scale photo on the previous page is a 3x enlargement of a portion of the October 6, 1972 U-2 9 x 9" color-infrared transparency. Forest harvest history has been delineated on this photo based upon interpretation of larger scale black-and-white photos dated 1936, 1962, 1968, and 1972. The enlargement is a good map base because the map units are generally sufficiently large that the symbolic legends do not obscure more than twenty-five percent of the image information associated with each map unit. Note the color tones characteristic of the various harvest periods: (1) present to five years; (2) six to eleven years; and (3) twelve years or more. Note also that the fan-like pattern associated with cable logging distinguishes this type of harvesting method from tractor logging which is characterized by nonlinear small gauge road patterns. The mylar overlays permit information regarding the various harvesting periods to be segregated (the bottom mylar sheet shows the oldest harvest areas). Supplementary information on erosion and revegetation problems can also be superimposed on the map base and related to harvest history data. Dotted lines on the topmost mylar overlay show some of the areas which have experienced soil mass movement in the recent past. Diagnostic characteristics which allow detection of the soil movement include (1) the roughly textured forest canopy along stream banks, known to indicate areas of active slides, (2) the brighter red reflectance near drainages often indicative of hardwood seral stages occupying recently stabilized slide areas, and (3) exposed soil exhibiting slumping or linear slide activity.

Figure 4.26. The 1:37,500 scale photo on the next page is a 3x enlargement of a portion of the April 4, 1973 U-2 9 x 9" color-infrared transparency. The area represented is the same as in Figure 4.25. Dotted lines indicate areas harvested since the October, 1972 photo was taken. In addition to monitoring the changes occurring over time, high altitude photos are also useful as a map base for supplemental resource data. In this figure the map units represent surface erosion classes as defined on California Cooperative Soil-Vegetation Survey maps covering the imaged area. Erosion class boundary lines were transferred from the maps to the image by means of a Bausch and Lomb Zoom Transfer Scope. Surface erosion hazard refers to the probable susceptibility of a soil to erosion on a thirty to fifty percent slope after significant disturbance of protective vegetative cover. Surface erosion classes are rated as: slight (S), slight to moderate (S-M), moderate (M), moderate to high (M-H), high (H), high to very high (H-VH), and very high (VH). Erosion class assignments in this figure have been corrected for slope classes greater and less than thirty to fifty percent.

Figure 4.26. (see preceding page)

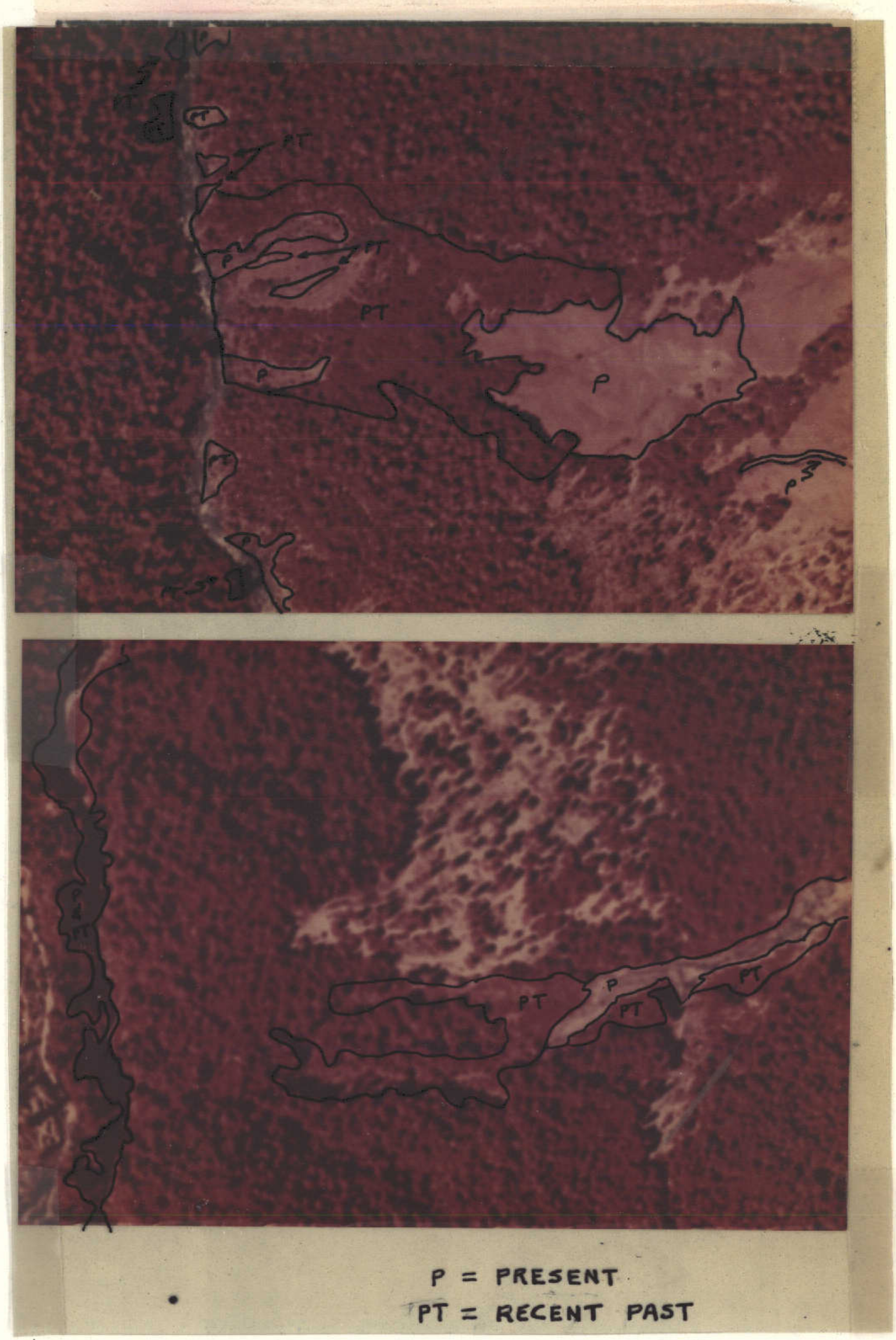

Figure 4.27. These 1:15,875 scale photos are made from a 2x enlargement of the April 4, 1973 U-2 9 x 18" color-infrared transparency. The areas shown correspond to portions of Figures 4.25 and 4.26. Prairie and forest areas presently undergoing soil mass movement are delineated as are forested areas which have experienced sliding in the recent past. Note how the increased spatial resolution of this image type allows improved detection and identification of recently-stabilized (hardwood-dominated) slide areas. Also among the features which are more readily identifiable are: active slumping in prairies, slides adjacent to road cuts, slides in forest stands along small streams, stand structure, stand density, water resources, and characteristics of the road network. The original transparency enlarged to a scale of 1:15,875 is a more useful map base for displaying management problems and resource features.

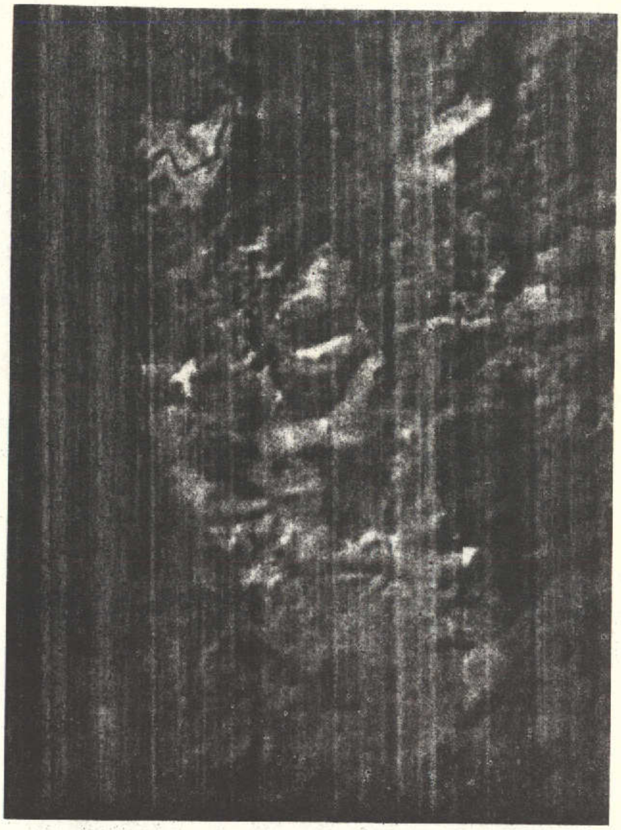

Figure 4.28. This 1:125,000 scale image is a 16x enlargement of a simulated color-infrared ERTS color composite. The negative was made by color combining the 9 x 9" black-and-white images (MSS Bands 4, 5, and 7) taken on October 27, 1972. The ground areas shown in Figures 4.25 and 4.27 are indicated above. Areas having homogeneous color and textural characteristics have been delineated, and may be identified as to harvest history by reference to the map base in Figure 4.25. Note the difficulties in distinguishing between harvested areas which are six to eleven years old, and those twelve years old or more. It is also difficult to differentiate between prairies and recently harvested locations. Active soil mass movement areas and potential soil movement locations (associated with Red alder stands near stream banks) are also very difficult to detect.

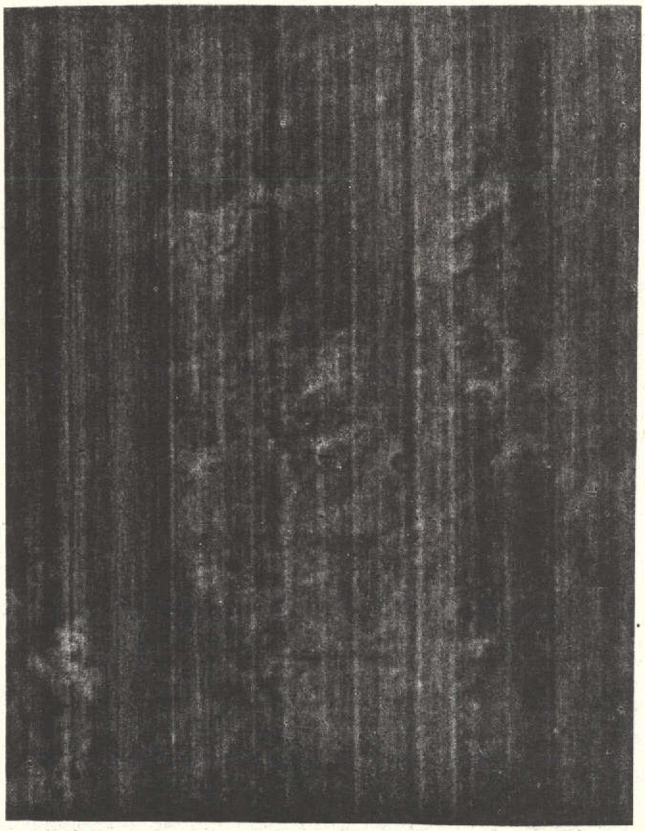

Figure 4.29. This 1:125,000 scale image is a simulated color-infrared composite made from ERTS bands 4, 5, and 7, taken on April 6, 1973. Areas which have been harvested since October, 1972, are indicated by dashed lines. Grassland vegetation (pink color) is metabolically active at this time of year and therefore is distinguishable from recently harvested areas. Note also that the areas harvested six to eleven years ago are now more distinguishable from those harvested twelve or more years ago. Harvest methods (tractor and cable) which are identifiable on the U-2 photo (Figure 4.25) cannot be seen in this image. Spring runoff sediment discharge can be seen in Redwood Creek's sediment plume above. Because of low streamflow in the autumn, sediment plumes are not apparent on the ERTS composite in Figure 4.28.

Figure 4.30. The above 1:125,000 scale image was obtained from an April 6, 1973 MSS Band 5 (1;1,000,000 scale) transparency. ERTS-1 Band 5 appears to be very useful in monitoring change in land use pattern, location and extent of recent harvesting activity, snow pack location, and sediment plume activity. However, these parameters are generally more readily detectable and identifiable on ERTS-1 color composites, though at two to three times the single band cost. For instance, note the difficulty in differentiating the areas harvested six to eleven years ago from other land categories in the above figure. However, note that Band 5 appears to be the best ERTS-1 image type examined to detect large slide areas in forest vegetation types. This situation can be be illustrated by reference to the large slide on the east side of Bridge Creek within circled area above (compare with the same area on the ERTS-1 color composites and Figure 4.27 [bottom]).

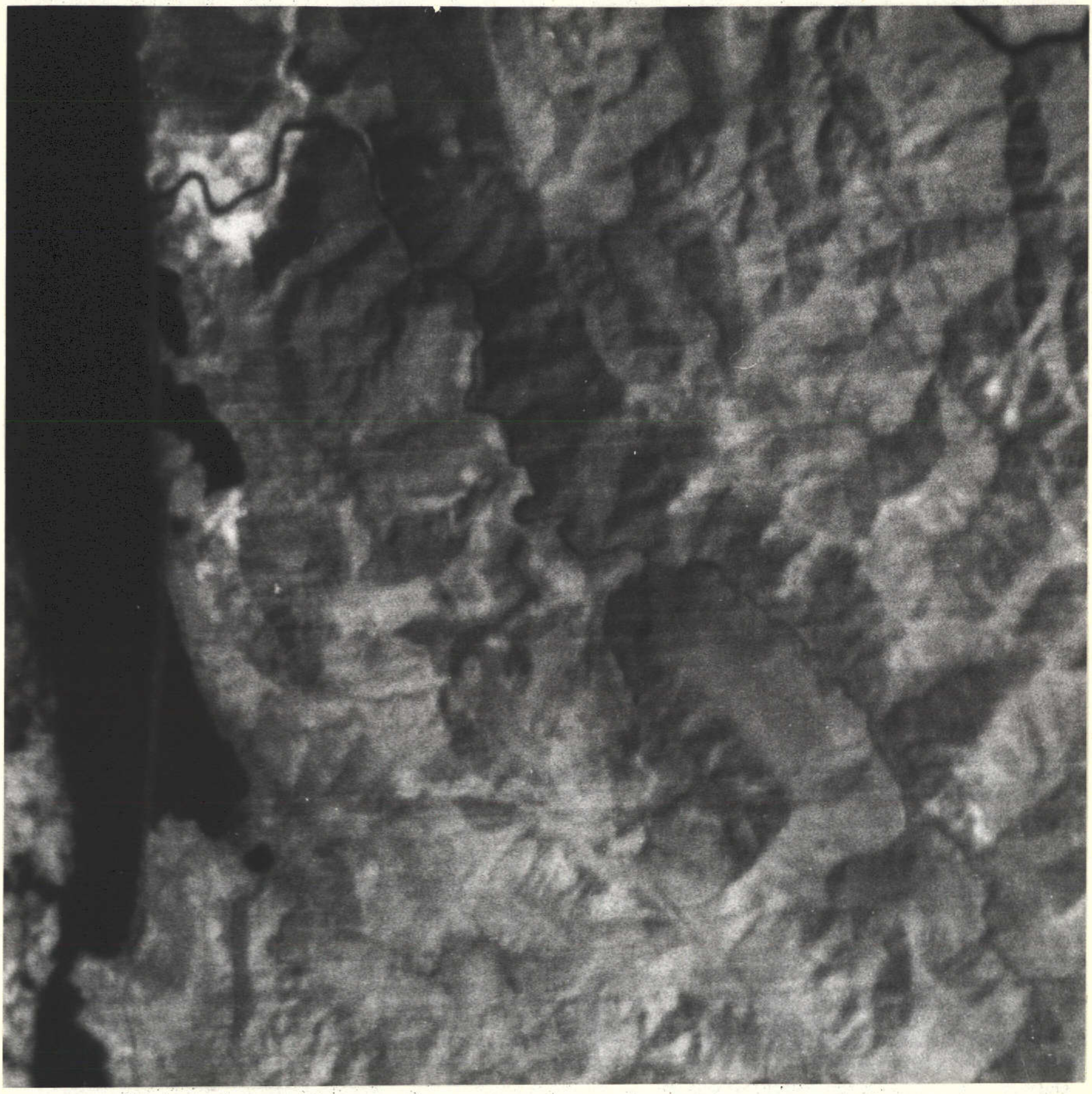

Figure 4.31. This 1:125,000 scale image was obtained from an ERTS-1 April 6, 1973 Band 7 (1:1,000,000) transparency. It is apparent that information on landform characteristics and the extent of bays, lagoons, and large stream channels is readily extractable from Band 7 imagery. However, Band 7 is generally not useful, in the region examined, as an information source for land use, vegetation type, period since forest harvest, or sediment plume detection. In the above figure note the general absence of harvest boundaries (except in the case of the twelve to seventeen year post-harvest areas and in some instances old growth forest adjacent to harvested areas), vegetation boundaries, and the sediment plume known to be present on the same date from Figure 4.30.

Company. Project reviews have been carried out in cooperation with the National Park Service. Additionally, the North Coast Regional Commission of the California Coastal Zone Conservation Commission has been briefed on this remote sensing project.

As a result of the enthusiastic response from these organizations the CRSR has prepared and sent to each a document describing the methods of obtaining and enlarging ERTS-1 and supporting high altitude U-2 imagery. The North Coast Commission and several of the wood products firms now plan to order imagery from Sioux Falls, S.D.

The major conclusions from the North Coast Test Site northern study area project based on manual image interpretation only are the following:

1. ERTS-1 multi-band color composite image types can be useful information sources for determining topographic position, general slope class, land use pattern, land use change, location and extent of recent and past harvesting activity, snow pack location, snow pack change, and river sediment plume activity.

2. ERTS-1 color composites can in some cases be used to map very broad categories of vegetative type and stand density. Some information on geologic units and the extent of bays, lagoons, and large stream channels may also be obtained from ERTS-1 color composite and band 7 image types utilized in this study.

3. ERTS-1 band 5 appears to be most useful for monitoring change in land use pattern, location and extent of recent harvesting activity, snow pack location, and sediment plume activity.

4. ERTS-1 images were not useful, or only indirectly useful, for location and characterization of resource management problem areas.

5. High altitude U-2 photography is generally very useful in the detection, delineation, and identification of resource management problem areas and ecosystem resource features. All three U-2 image types examined are especially good information sources for the analysis of (a) active soil mass movement areas, (b) detection of present and potential locations of bank undercutting via stream action, and (c) analysis of site factors which would dictate the appropriate harvesting techniques to employ for a given location. In these cases the 1:15,875 U-2 image format has a detectability rating at least one class above that for the 1:37,500 images. The larger scale 1:15,875 photos are also the best U-2 information source among those examined for the detection, delineation, and identification of potential soil mass movement areas and potential road failure locations.

6. Most resource features, except species composition and slope class, were interpretable from the U-2 photo enlargements. The 1:15,875 U-2 image allowed the greatest ease of detection or assessment of forest harvest methods, forest regeneration methods, and dates of harvest.

The 1:15,875 photo also gave the highest resource feature identification rating.

7. The 1:15,875 U-2 image type appears to be an optimal map base for the widest array of management problems characteristic of the California north coast. U-2 1:37,500 enlargements are less useful as management problem map bases, while ERTS-1 1:125,000 enlargements are not appropriate for this task.

The ranking of these types of imagery in terms of their utility as a resource feature map base follows the same order as above. However, the U-2 1:37,500 prints are often useful map bases depending on the variability of the resource parameter. ERTS-1 1:125,000 images have good map utility for recent forest harvest activity location and land use pattern delineation.

8. The optimum combination of high altitude and earth orbital imagery utilized by a resource manager in the California north coast region will depend on the level and type of his information needs, and the cost efficiency of utilizing these remote sensing techniques. One optimum combination for organizations with large land management responsiblities is a U-2 1:37,500 map base system, supplemented by (a) U-2 1:15,875 image types of special interest areas and (b) periodic ERTS-1 imagery for use in monitoring general land condition change over a regional area. Conventional larger scale imagery and supplemental data could be integrated with the above combination as required to meet management objectives.

4.3.4 Conclusions -- North Coastal Zone

1. One of the greatest applications for analysis of ERTS imagery is in the detection of changes in the resource base over time. Admittedly, the changes must be resolvable in order for manually interpreted ERTS imagery to be effective in evaluating the nature and extent of the change. Our studies demonstrate that harvesting activities in the timbered regions of northern California could be monitored with ERTS imagery. Also, a determination of the location and an estimation of the size of the harvested area could be made. Other resource changes which can be monitored include: sediment plume size and direction, greening and drying of annual herbaceous vegetation, location and amount of irrigated crops, stage of development of marsh vegetation, and changes in the size of large ponds and lakes. For most of the changes that can be detected or monitored, supporting information from either aerial photographs or ground sampling is required in order to establish the significance of the change.

2. Whereas it has been demonstrated that broad vegetation types can be mapped using ERTS imagery, the utility of this broad resource information is limited for the resource managers in the north coast. The primary usefulness of the map information derived from the ERTS

imagery in the north coast is in the display of land use types throughout large regions. The ERTS imagery provides a regional perspective of resouce types and management units and allows the resource types to be evaluated in terms of their relationship to each other and related to the different types of land management practices. The ERTS imagery can be rectified and enlarged to a workable map scale of 1:250,000 or 1:125,000, thus providing a map base for resource types upon which other sources of map information can be superimposed.

3. User groups within the north coast area (federal land managers, county planners, private resource managers, etc.) generally require specific kinds of resource information for a localized area. The majority of their informational requirements can be satisfied through interpretation and analysis of U-2 photography obtained from 65,000 feet and at two scales, 1:32,000 and 1:120,000. Evidence of the utility of the U-2 photography is to be found in the vegetation type maps, timber harvesting maps, land use maps, and problem detection maps which have been generated and used by resource managers.

4. Preliminary analysis of computer classification of ERTS data of the north coast demonstrates that cost-efficient determinations can be made of the location, distribution and status of resource management problems. Point-by-point discriminate analysis of ERTS-1 tapes, together with information gained from manual interpretation of ERTS-1 imagery and U-2 photography, and combined with supplemental sources of information would allow inplace modeling of ecosystem processes important to land managers and land resource policy makes. Personnel from the Redwood National Park have indicated a strong desire to develop an operational program which would exploit the benefits of satellite data in models which simulate vegetation production and water yield.